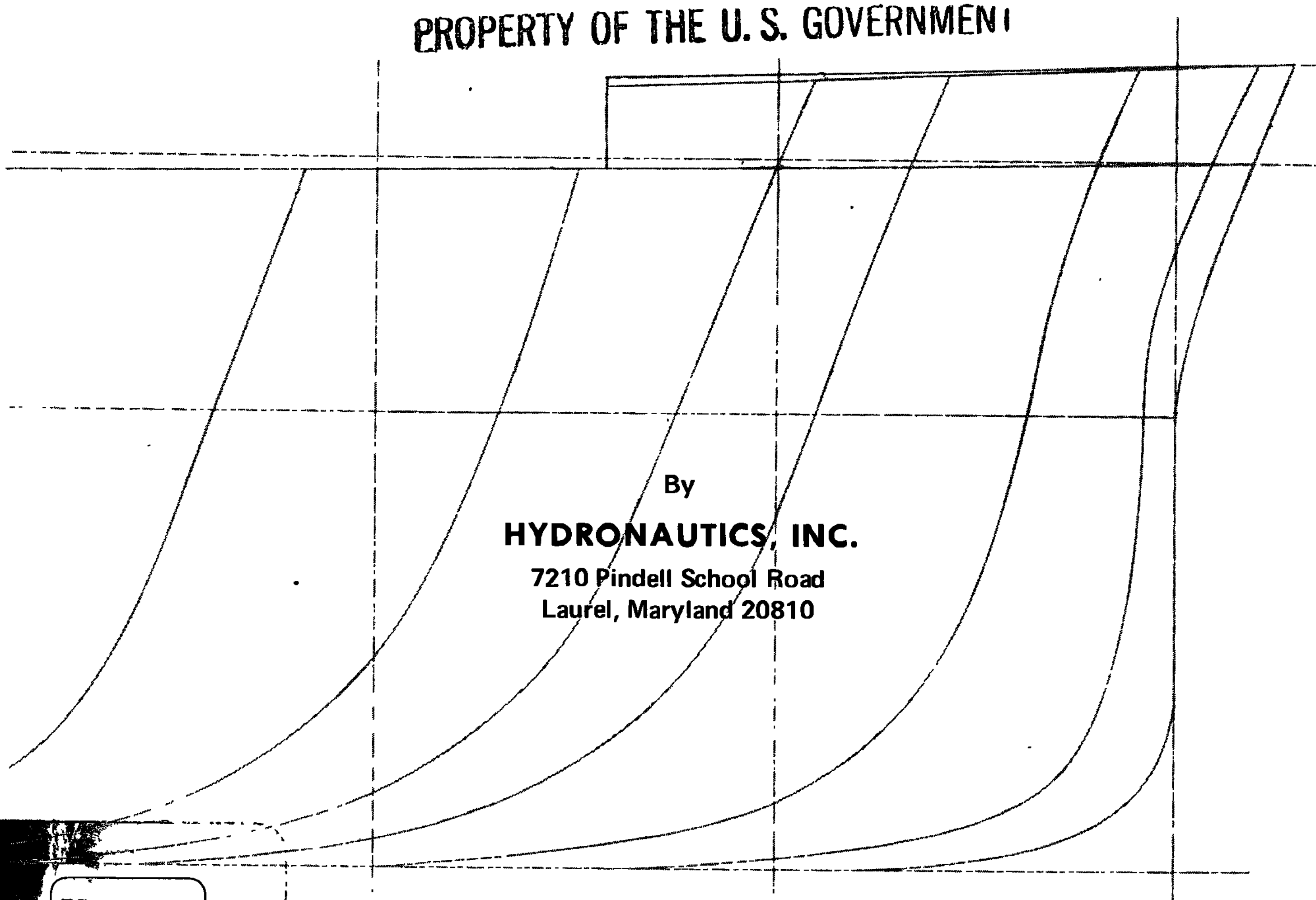
CONCEPT DESIGN AND COST ANALYSIS OF RESTRICTED DRAFT DRY BULK CARRIERS

A REPORT SUBMITTED TO THE

U.S. ARMY ENGINEER INSTITUTE FOR WATER RESOURCES

Kingman Building
Fort Belvoir, Virginia 22060



By

HYDRONAUTICS, INC.
7210 Pindell School Road
Laurel, Maryland 20810

UNDER
CONTRACT NO. DACW73-73-C-0043

NOVEMBER 1973

IWR CONTRACT REPORT 74-1

1-HL

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INSTITUTE FOR WATER RESOURCES, CORPS OF ENGINEERS
KINGMAN BUILDING
FORT BELVOIR, VIRGINIA 22060

REPLY TO
ATTENTION OF:

IWRDR

24 May 1974

SUBJECT: IWR Contract Report 74-1, "Concept Design and Cost Analysis of Restricted Draft Dry Bulk Carriers"

Recipients of Subject IWR Report

1. The attached report by Hydronautics, Inc. is being distributed to a limited number of agencies and private parties and firms to whom the subject matter is considered to be of interest from a professional, program, or business point of view.

2. The report develops and describes design characteristics of restricted draft dry bulk carriers and compares the operating and capital costs of such carriers with carriers of conventional design.

3. The restricted draft concept is relevant to ocean going carriers whose conventional design draft would exceed the permissible draft in ports and channels which they would serve. This condition exists at a number of U. S. East and Gulf Coast ports and channels through which dry bulk import and export commodities move, such as grains, coal, phosphate rock, and iron ore.

4. Copies of the report are available from The National Technical Information Service, Department of Commerce, Springfield, Virginia 22151, for $5.00, identification number AD 777-884.

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A report submitted to the

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Copies may be purchased from:

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U. S. Department of Commerce
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November 1973

IWR Contract Report 74-1

NOTE FROM THE INSTITUTE FOR WATER RESOURCES

Federal responsibility for planning, constructing, and maintaining harbor and channel depths, and responsibility for reviewing and issuing permits for non-Federal developments in navigable waters of the United States resides primarily with the Army Corps of Engineers. As a result, the Corps of Engineers is concerned with the recent and rapid increases in ship size and water depth requirements. The Institute for Water Resources has sponsored several studies pertaining to deepwater ports, three of which were completed in 1971-73, i.e., FOREIGN DEEPWATER PORT DEVELOPMENTS, by Arthur D. Little Inc., and U. S. DEEPWATER PORT STUDY and INSTITUTIONAL IMPLICATIONS OF U. S. DEEPWATER PORT DEVELOPMENT FOR CRUDE OIL IMPORTS, by Robert D. Nathan Associates, Inc. The Corps of Engineers has also completed detailed studies of the need for deepwater ports in three major coastal regions--the North Atlantic, Gulf of Mexico, and the Pacific.

The present study on CONCEPT DESIGN AND COST ANALYSIS OF RESTRICTED DRAFT DRY BULK CARRIERS was an outgrowth of the U. S. DEEPWATER PORT STUDY. That study included a report by Hydronautics, Inc. entitled CHARACTERISTICS OF TANK VESSELS FOR RESTRICTED DRAFT SERVICE. A computer design program developed by Hydronautics was employed to determine design characteristics and estimated costs for tankers of varying deadweights, with drafts from 35 feet to 95 feet and deadweight capacities to 500,000 tons.

A major finding of the original Hydronautics study was that restricted draft design offered a limited but significant opportunity for increasing vessel capacity within given draft limitations, with a favorable trade-off between economies of scale and diseconomies of restricted draft design.

The scope of the study was limited. Beyond the exercise of good design judgment, no attempt was made to obtain optimized ship characteristics and corresponding costs. It was recognized that for this purpose more detailed studies would be required. The U. S. DEEPWATER PORT STUDY recommended additional research into the economic, engineering and operational characteristics and parameters applicable to the use of restricted draft vessel design.

Other findings of the U. S. DEEPWATER PORT STUDY suggested to IWR that further study of restricted draft vessel design and costs should be addressed specifically to dry bulk or combined carriers with drafts corresponding to typical existing channel depths, or depths which in some instances would be attainable at reasonable economic and environmental costs. The relevant findings were (a) that the depths to be required for crude oil tankers were such as to rule out channel deepening in some coastal areas as a feasible solution relative to off-shore terminals, and (b) that channel deepening or the use of restricted draft vessel design appeared to be economically feasible for dry bulk commodities relative to off-shore facilities.

In December 1972, IWR contracted with Hydronautics, Inc. for the present study. The scope of work required the development of designs for three discrete dry bulk vessels corresponding to three project drafts, in sufficient depth to insure feasibility of the design and provide a firm basis for cost estimating. The preliminary characteristics of each design were to be selected from a computer study, directed to development of the maximum feasible capacity for a given draft, consistent with optimization to a selected economic criterion.

Because of the unusual hull forms likely to be selected, the contractor was required to obtain the advice of the American Bureau of Shipping with respect to structural requirements and the U. S. Coast Guard with respect to current U. S. and International Maritime Consultative Organization requirements. As stated in the report, this was done. But this process of consultation and review did not, and could not, result in a technical determination of important operational characteristics of the design vessels, particularly directional stability, maneuverability, and seakeeping. The requisite data for such a determination were not available, and could only be obtained through model tests or operational experience. The Coast Guard specifically drew attention to the maneuvering difficulties that would be experienced by vessels of low length to beam ratio and high beam to draft ratio. These and other problem areas are identified and discussed in the report.

However, it is important that these problems be viewed in the perspective of the state of the art of restricted draft design as evidenced by vessels in operation or under construction.

Variations in deadweight capacity of vessels with comparable drafts are a characteristic of the existing world fleet of bulk carriers. Examination of Figure 1, for example, which plots the deadweight and draft of a number of existing vessels, discloses a range of approximately 20,000 tons for vessels of about 45 feet draft, and over 50,000 tons for vessels of about 55 feet. As shown in Figure 1, the project design vessels in this study exceed the deadweight of any of the vessels in the existing fleet for which data are plotted.

Hitachi Zosen, a Japanese ship builder, reports orders for 400,000 ton tankers with a loaded draft of 72 feet and length/breadth ratio of 5. The company states that the new hull form was successfully tested for maneuverability, resistance, propulsion, etc., using a 90 foot long manned model. Model basin tests of ships of these extreme ratios are also being conducted in the United States. The fact that large tankers of these dimensions have been ordered is encouraging evidence that the project design vessels selected for this study may not be significantly beyond the state of the art for vessels of such size.

It should be noted, however, that applications suited to large tankers operating essentially in open deepwater may not be representative of potential applications for dry bulk carriers operating in restricted channels in harbors. Some modifications in dry bulk design may be warranted.

The prospective savings in vessel costs raise interesting and fundamental questions pertaining to benefit/cost analysis of channel deepening projects. The use of restricted draft design may be viewed as an alternative to the deepening of channels and harbors where a requirement for such deepening exists to accommodate vessels of conventional design. Either alternative involves economic costs and benefits which need to be evaluated. The methodology and concepts to be employed in this type evaluation, and the circumstances under which it is to be applied, should be a subject for future consideration.

The present report does not provide the data that would be required for such evaluation. It is rather a preliminary study which demonstrates in a broad way the economic characteristics of vessels of conventional and restricted draft design, and approximates the design parameters that should probably govern the application of the restricted draft principle.

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ACKNOWLEDGMENTS

In addition to the authors, several individuals, private companies and government agencies provided input to the study. Mr. Ralph Trisko of the Institute for Water Resources served as the sponsor's project manager and provided guidance throughout the study, particularly in the definition of economic criteria and cost analysis.

Personnel of the U. S. Coast Guard, Office of Merchant Marine Safety, offered useful comments on intact and damaged stability characteristics of the unusual hull geometry and configuration of the restricted draft forms. The American Bureau of Shipping served as consultant to HYDRONAUTICS, Incorporated and reviewed structural drawings for general feasibility.

Mac-Gregor Comarain, Inc. of Cranford, New Jersey provided valuable design and cost information for procurement of dry bulk carrier hatch covers.

At HYDRONAUTICS, Incorporated, Mr. William Lindenmuth carried out modifications to the computer design program and initiated the parametric studies. Mr. John Slager prepared the final speed and power estimates for the concept designs.

1.0 INTRODUCTION

The study discussed in this report was directed toward an assessment of feasibility, development of concept design, and estimation of costs of a series of restricted draft dry bulk carriers for service to ports of the United States. Existing and recommended water depths of major coastal ports will permit operating drafts in the 35 ft to 55 ft range. As shown in Figure 1, existing conventional bulk carriers designed for these drafts may reach deadweight capacities of about 40,000 tons to 160,000 tons, respectively. Capacities of existing bulk carriers and combination carriers, i.e., ore-bulk-oil (OBO) and ore-oil carriers, now exceed the 250,000 DWT level in foreign service where deep draft ports are available.

The cost of transporting bulk commodities is reduced significantly with increased size of vessel. To obtain lower bulk transport costs by use of larger vessels, the United States faces the following alternatives:

a. Conduct an extensive and costly program of channel and harbor dredging.

b. Construct offshore terminals for deep draft vessels, with provision for trans-shipment to mainland terminals via pipeline, conveyor, or feeder vessels.

c. Develop new designs of large bulk carriers specifically designed for service to restricted draft U. S. ports.

Alternatives (a) and (b) are well covered in the literature, Reference 1 in particular. This study is directed toward alternative (c), the development of restricted draft bulk carriers.

In a previous study, Reference 2, the feasibility of building restricted draft tank vessels was investigated by use of a computer design program. The favorable conclusions reached in the study were dependent upon the validity of the extrapolation of conventional ship design data. The current study was defined to verify and expand the earlier analysis, specifically applied to dry bulk carriers.

The current study was conducted in the following distinct phases:

1. Parametric computer design study - Characteristics of three candidate restricted draft designs, corresponding to three drafts selected by the sponsor, were determined by an optimization study, using a computer design program.

2. Designs of the three candidate vessels were carried out in sufficient detail to permit verification, or modification of, the computer designs and to provide a basis for procurement cost estimating.

3. Resulting concept designs and costs were compared with equivalent designs of conventional vessels of the same deadweight capacity.

2.0 SUMMARY OF FINDINGS

Results of the study, including parametric analysis, technical feasibility, design concepts, costs, and problem areas, are discussed fully in this report. Basic findings of the study are summarized in the following paragraphs.

2.1 Advantages of Restricted Draft Design for Dry Bulk Carriers

For a given draft restriction, deadweight increases of 30 percent to 50 percent above conventional practice may be obtained for a reasonable departure from conventional ship proportions. For the three specific draft limitations assumed for the study, the following gains in deadweight capacity over conventional practice may be realized:

Draft	Deadweight, Max. Conventional Design	Deadweight, Max. Restricted Draft Design
35 ft	40,000	60,000
45 ft	85,000	125,000
55 ft	170,000	225,000

Conversely, for a given deadweight, draft reductions of about 15 percent from conventional design practice may be obtained by adopting restricted draft hull geometry. This is illustrated by the following comparison:

Deadweight	Normal Deep Draft	Restricted Draft
60,000	40 ft	35 ft
125,000	53	45
225,000	65	55

2.2 Costs of Restricted Draft Design Bulk Carriers

For a given deadweight, capital costs of restricted draft dry bulk carriers will be somewhat greater than corresponding costs of deep draft vessels, as illustrated by the following comparison derived from the study:

Deadweight Nominal	Capital Cost, $/DWT Deep Draft	Capital Cost, $/DWT Restricted Draft	Percent Increase
60,000	$162.48	$164.13	+1.0
125,000	120.36	124.31	+3.3

The corresponding penalties in required freight rates are of the same order.

For a given draft restriction, however, the higher deadweight restricted draft vessel represents a significant cost advantage relative to a conventional vessel of lesser capacity. This is illustrated by the following example derived from the parametric and concept design studies for a constant 45 ft draft, which represents the mean range of drafts considered.

Item	Conventional Design	Restricted Draft Design
Design method	Computer design	Concept design
Deadweight	80,000	126,970
Capital cost, $/DWT	$141.26	$124.31
% reduction	-	12.0
* Required freight rate, mils/ton-mile	0.4041	0.3566
% reduction	-	11.8

* For 5000 mile voyage, 5000 tons/hr cargo handling rate, utilization = 0.667.

Relative to conventional designs, total operation and support costs, excluding fuel, are about 1-1/2% to 3-1/2% higher for the restricted draft designs. Fuel costs are directly proportional to power requirements which tend to be higher for restricted draft designs.

2.3 Problem Areas; Research and Development Requirements

Certain problem areas are recognized in the study and will require further engineering development prior to final design and construction of restricted draft dry bulk carriers. None of these items is expected to be a barrier to development of restricted draft shipping.

Hull Form Development and Powering - Hull forms for restricted draft service will require further development and appropriate model testing will be required to obtain reliable estimates of powering requirements.

Directional Stability and Control - Large full form vessels, with low values of the ratio length/breadth, tend to be directionally unstable. Comprehensive studies, including model testing, will be required to assess the magnitude of the problem and to develop practical solutions.

Seakeeping - Unusually high initial stability, and consequent short roll periods and high roll accelerations, are characteristic of the proposed restricted draft forms. An assessment of the effect on ship, cargo, and crew should be made for each design and consideration should be given to alternative hull arrangements to maximize height of the cargo and ballast centers of gravity.

Structural Design - The unusual hull proportions and unusual arrangements proposed will require detailed study with respect to classification society requirements and basic structural design analysis.

Cargo Handling - The compatibility of the unusual hull dimensions, breadth in particular, with existing terminals and cargo handling facilities must be reviewed for each case.

Construction and Drydocking Facilities - The unusually wide hull forms, particularly in the case of the higher deadweight vessels, may require modification of existing building facilities. Availability of appropriate drydocking facilities should also be investigated as part of each design study.

3.0 SELECTION OF CHARACTERISTICS OF CANDIDATE DESIGNS

3.1 Assumptions

Characteristics of candidate designs for three drafts, 35 ft, 45 ft, and 55 ft, were obtained from the results of a parametric study, using the HYDRONAUTICS proprietary concept design computer program described in Appendix A. The following requirements and assumptions were held for the entire study:

Design drafts	35 ft, 45 ft and 55 ft
Voyage lengths, one-way	1,000 to 15,000 miles
Cargo handling rates	1,250 and 5,000 tons/hr
Utilization (i.e., % time transporting cargo)	50 and 66-2/3%
Crew size	27
Propulsion	Single screw, geared steam turbine, 50,000 SHP max.

Certain physical boundary conditions were imposed on the ship geometry to insure that extrapolation beyond current state of the art is reasonable. The following hull form ratio limits were adopted:

$$\frac{\text{Length}}{\text{Depth}} = \frac{\text{LBP}}{\text{D}} \leq 15$$

$$\frac{\text{Length}}{\text{Breadth}} = \frac{\text{LBP}}{\text{B}} \geq 5$$

The inter-relationship of the ratios LBP/B, beam/draft, (B/T), and block coefficient, C_B, was recognized and an approximate means for establishing reasonable limiting values to these ratios and coefficients was developed. Published and proprietary literature, with respect to characteristics of full form vessels, was examined to develop the following limiting linear relationship between B/T and C_B:

$$B/T = 3.25 \text{ @ } C_B = 0.85$$

$$B/T = 4.00 \text{ @ } C_B = 0.75$$

Intermediate B/T values were interpolated. This relationship is clearly not rigorous in that no cognizance is taken of the effects of L/B variation. However, B/T is permitted to increase for finer values of C_B, which reflects actual practice with restricted draft fine forms such as LNG carriers.

Cost estimating and analysis follows the relationship established by Dart in Reference 3. To escalate the computed values obtained by the Dart relationships, an escalation factor of 1/2% per month, from June 1970 to June 1973, was applied. This amounts to an 18% increase over the computer values. This escalation was also applied to costs for stores and supplies, subsistence, and maintenance and repair.

Assumed cost relationships, including modifications to the Dart formulations, are given in Appendix B.

3.2 Selection of Characteristics

For the computer aided parametric study, the following matrix of input variables was established for each design draft:

Deadweight	Minimum of four values per draft
Speeds	14,16 and 18 knots, for each deadweight
Lengths	four values per deadweight-speed combination
Block coefficient (C_B)	five values per length

3.2.1 35 ft Draft Design Study

Computer design and cost studies for the 35 ft draft design were prepared for deadweight values from 30,000 tons to 70,000 tons, for service speeds of 14 to 18 knots. With respect to practical considerations, deadweight values of 65,000 tons and larger, and below 45,000 tons were eliminated. The larger designs exceed one or more of the physical boundary conditions noted in earlier discussion, and the smaller vessels would have insufficient intact stability.

Figure 2, shows the results graphically for vessels of 45,000 DWT, 52,500 DWT and 60,000 DWT, for speeds of 14 to 18 knots. All curves on this diagram identify feasible ships, as defined in this study. From this diagram, a 60,000 DWT, 15 knot vessel was selected. This deadweight capacity is in the region of the maximum feasible ship size for 35 ft draft, based on the assumed boundary conditions. Figure 3 is a plot of required freight rate (RFR) as a function of length and block coefficient, for 60,000 DWT and 15 knots

Note that Figures 2 and 3 were prepared for the following conditions:

Capital cost basis	=	each of 5 ships
Cargo handling rate	=	5,000 tons/hr
Utilization	=	0.667
Voyage length	=	5,000 miles, one way

The results of this study for all input conditions clearly favored the maximum feasible design, and variations in the above conditions had no effect on the selection of the optimum vessel.

From the results of this study, the principal characteristics summarized in the following tabulation were selected from the computer output for concept design:

Length, B.P.	740' - 0"
Breadth, mld.	131' - 0"
Depth, mld.	52' - 0"
Draft, design, mld.	35' - 0"
Displacement, total	76,650 tons
Light ship weight, about	16,650 tons
Deadweight, total, about	60,000 tons
Cargo cubic capacity, 100%, about	2,945,000 cu ft
Cargo stowage factor, 5,000 mile voyage, about	50 cu ft/ton
Shaft horsepower, A.B.S. max.	15,000
Service speed (trial speed at 80% max SHP, full load displacement), about	15 knots

Complement		27
Preliminary form coefficients		
C_B	0.790	
C_P	0.793	
L/B	5.65	
L/D	14.23	
B/T	3.74	
Investment cost, each of five ships		$10,629,000.
$/DWT		177.15

3.2.2 <u>45 ft Draft Design Study</u>

Computer design and cost studies for the 45 ft draft design were prepared for deadweight values from 45,000 tons to 135,000 tons, for service speeds of 14 to 18 knots. The 135,000 DWT study resulted in designs which exceeded one or more of the assumed physical boundary conditions noted earlier and the 45,000 DWT design characteristics indicated insufficient intact stability. The results are summarized in Figures 4 through 7 for the following conditions:

Deadweight	80,000, 115,000 and 125,000 tons
Service speeds	14 to 18 knots
Voyage lengths	5,000 and 10,000 miles, one way
Cargo handling rates	5,000 tons/hr, utilization = 0.667
and utilization	1,250 tons/hr, utilization = 0.5
Capital cost basis	each of 5 ships

The combination of cargo handling rates and utilization values selected for the plots represent the limits of ship productivity studies.

For all conditions, Figures 4 through 7 indicate that the near-optimum design is a 115,000 DWT vessel operating at a service speed of 15 knots. The near-maximum feasible vessel at this draft would have a capacity of 125,000 DWT, with a near-optimum service speed of 16 knots. Principal characteristics of the two selected versions of the 115,000 DWT and

125,000 DWT designs are summarized in Table 1. Corresponding cost data is summarized in Table 2. Additional data are given in Figures 8 and 9 for the 115,000 DWT and 125,000 DWT designs respectively.

It should be noted that the plots of Figures 4 through 7 only include data for feasible designs which meet the boundary conditions established earlier. The locii of minimum-feasible RFR values plotted in Figures 8 and 9 identify minimum RFR designs which meet feasibility constraints. Where lower RFR values are plotted for particular ship lengths, the data was included to provide a means for fairing the curves of RFR versus C_B.

The RFR advantage of the 115,000 DWT vessel, relative to the 125,000 DWT design, varies from about 4-1/2% for the 5,000 mile voyage and lowest value of cargo handling rate, to about 2-1/2% for the 10,000 mile voyage and highest cargo handling rate. Initial investment cost in terms of $/DWT is about 6.8% higher for the 125,000 DWT design, relative to the smaller vessel.

The favorable showing of the smaller vessel, contrary to the experience with vessels of normal proportions, is explained in terms of basic characteristics of the two designs. As shown in Table 1 the ratios L/B and L/D are lower for the 115,000 DWT vessel than for the 125,000 DWT design. The value of L/D = 14.10 for the 125,000 DWT design, for example, is near the maximum value for existing seagoing vessels currently in operation. This characteristic infers a high effective longitudinal steel requirement for a given size of vessel. This is further illustrated by a comparison of the following ratios for the two vessels:

DWT	115,000	125,000
DWT/displacement	0.816	0.794
Hull steel/displacement	0.181	0.214

It should be noted that the comparison would strongly favor the larger vessel if the values of the ratio L/D were similar, i.e. if the 125,000 DWT vessel were designed for 50 ft to 55 ft normal operating drafts.

Regardless of the near-optimum position of the 115,000 DWT design, the 125,000 DWT/16 knot design was selected for further study since primary study interest is in the development of dry bulk carriers for restricted draft operation. Capacities of existing bulk carriers designed for this draft are in the range of about 70,000 DWT to 90,000 DWT and selection of the larger design would best serve the study objective.

3.2.3 55 ft Draft Design Study

Computer design and cost studies for a 55 ft draft bulk carrier were prepared for deadweight values from 100,000 tons to 250,000 tons, for service speeds of 14 to 18 knots. A 250,000 DWT study resulted in designs which exceeded one or more of the assumed physical boundary conditions stated earlier and the 100,000 DWT design characteristics indicated insufficient intact stability.

The study results are summarized in Figures 10 through 13 for the following conditions:

Deadweight	150,000, 175,000, 200,000 and 225,000 tons
Service speeds	14 to 18 knots
Voyage lengths	5,000 and 10,000 miles
Cargo handling rates and utilization	5,000 tons/hr, utilization = 0.667 1,250 tons/hr, utilization = 0.5
Complement	27
Capital cost basis	each of 5 ships

As in the case of the 45 ft draft design, the selected combinations of cargo handling rates and utilization represent the limits of ship productivity studied.

The data point for a 160,000 DWT, 16 knot design was obtained from an independent random search. Data for speeds above 16 knots are not plotted for the 200,000 DWT and 225,000 DWT designs because the required power exceeded the 50,000 SHP limit assumed for this study.

For all conditions, Figures 10 through 13 indicate the range of near-optimum designs to be of about 150,000 DWT to 160,000 DWT at 16 knots or about 175,000 DWT at 15 knots. The near-maximum feasible vessel at this draft would have a capacity of 225,000 DWT, with a near-optimum service speed of 15 knots. Principal characteristics of the 160,000 DWT/16 knot vessel are compared with the 225,000 DWT/15 knot design in Table 3. Corresponding cost data is summarized in Table 4.

The cost differences between the minimum RFR and the maximum feasible designs is significant, covering the following range of values:

Investment cost	5.5%
RFR, 10,000 mile voyage	6.5% to 11.6%
RFR, 5,000 mile voyage	7.9% to 16.3%

Accordingly, selection of the near-maximum feasible DWT vessel for this draft was not proposed.

Since the difference in RFR between the maximum and optimum designs is relatively great, a compromise design, the 200,000 DWT/15 knot vessel, was selected.

Characteristics and costs of the optimum 15 knot and 16 knot designs are summarized in Tables 3 and 4, respectively. The 15 knot version is the preferred version by a small margin in RFR and by a significant 3-1/2% in investment costs. This design is, in fact, lower in initial cost in terms of $/DWT than the 160,000 DWT design.

Relative to the 160,000 DWT design, the costs of the recommended designs are within the following range of values:

Investment cost in $/DWT	-3.6%
RFR, 10,000 mile voyage	+0.7% to 3.1%
RFR, 5,000 mile voyage	+1.2% to 5.5%

Additional data for the 200,000 DWT/15 knot design is given in Figure 14, containing plots of RFR versus C_B and LBP.

4.0 CONCEPT DESIGNS

Principal characteristics selected from the computer design study were assumed as the basis for development of three corresponding concept designs by using conventional design methods. The more detailed design effort was intended to provide a verification of the computer design output and to further the investigation of the feasibility of restricted draft design concepts for dry bulk service.

4.1 Requirements and Criteria

The following requirements and criteria were established for the three designs:

Cargo	Light bulk stowage factor ≥ 47 cu ft/ton, for homogeneous loading Ore @ 12 cu ft/ton and 18 cu ft/ton
Cruising radius	Approximately 15,000 miles

Trim conditions
- Full load departure, trim ≅ 0' - 0"
- Full load arrival, trim ≤ 0.35% L.B.P.
- Ballast trim ≤ 1% L.B.P.

Complement 27

Regulatory requirements to suit American Bureau of Shipping and U. S. Coast Guard for the following:

"B-60" freeboard.
One-compartment subdivision and damaged stability standard.
Grain stability to permit operation with one slack hold at maximum hold waterplane inertia.
Ballast capacity ≥ 40% DWT, excluding peak tanks.

4.2 Design Summary

Principal characteristics of the three concept designs are summarized in Table 5. The estimated light ship weights and centers are summarized in Tables 6 and 7, and hull form characteristics in Table 8. The discussion in this section is generally applicable to the three designs and design differences will be considered in later sections of this report.

This discussion is limited to a brief consideration of basic characteristics of the vessels and discussion of unusual characteristics. No attempt has been made to select and describe the large number of equipment items which form the machinery and outfit components of a bulk carrier. Such items are common to conventional as well as restricted draft designs and selection of such equipment would have no significant effect on the results of this study.

4.2.1 Draft, Deadweight and Cubic Capacity

The three design configurations resulted from an optimization study based entirely on cost criteria, subject to the imposition of physical restrictions. As a result, freeboard requirements for "B" or "B-60" tabular freeboard would permit loading the vessels deeper than the 35 ft, 45 ft, and 55 ft respective design drafts. Early in the design process, it became evident that the computer design configuration was optimistic with respect to cargo hold capacity and a small depth increase was required in each case to obtain the required stowage factor. Two drafts were defined for the three vessels: the required service draft and a somewhat greater scantling draft for structural design purposes to provide for a small design margin. Scantlings were not provided for loading to the full freeboard draft which would be permitted by the current Load Line Regulations, Reference 4.

4.2.2 Arrangement

The three vessels are similarly arranged with nine cargo holds, short forecastle forward, machinery and all accommodations aft. An unusual afterbody hull form was adopted for compatibility with the full form, restricted draft requirement and it was necessary to modify the double bottom configuration in the after holds. In all cases, some fore and aft slope of the inner bottom was permitted, and double bottoms of unusual depth were required in the after locations.

Water ballast is carried in upper and lower wing tanks, and in the cargo hold double bottom. For the larger vessels, a ballast deep tank is provided forward, immediately aft of the forepeak. To provide for some design margin in calculation of the ballast loading conditions, peak tank capacities were not included in the computations.

Fuel bunkers are located in deep tanks within the machinery spaces for the three designs. Computations for trim and bending moment in the ballast condition indicated that acceptable conditions could be obtained with this arrangement.

4.2.3 Hull Form

The parent hull form adopted for the three designs is shown in the Lines Plan, Dwg. No. 7330-301. This drawing is specific to the 200,000 DWT design but is typical of the three hull forms.

The forebody is of a modified cylindrical bow geometry which has been successfully applied to large full form vessels, with characteristically high values of C_B and low values of L/B, i.e., $C_B > 0.80$ for $L/B < 6.0$. With respect to construction cost, this bow configuration is preferable to the bulbous bow designs provided for many of the current generation of dry and liquid bulk carriers.

The afterbody hull form is of unusual configuration, with broad, flat sections and long sloping buttocks. This form offers particular promise for hulls with values of $B/T > 3.0$.

4.2.4 Machinery

Propulsion machinery will be a conventional single screw geared steam turbine plant for all three vessels, designed to operate with steam at 850 psig and 950°F at the superheater outlet. Estimated all-purpose fuel rate at sea will be about 0.48 lbs/SHP-HR. Propulsion machinery in all cases will be arranged with turbine and gears forward and boilers aft. Single plane arrangements of turbine, gears and condenser, as manufactured by the General Electric Company, are compatible with this arrangement and the unusual afterbody hull form.

The vessels will be equipped with centralized control to permit limited operation of the main propulsion plant from the bridge. The plant controls and arrangement will be such as to permit a one man watch under normal operating conditions.

The electric plants for the three designs will consist of the following units:

Item	60,000 DWT	125,000 DWT	200,000 DWT
1 - Ship's service turbo-generator	750 KW	1,000 KW	1,000 KW
1 - Standby diesel-generator	500	750	750
1 - Emergency diesel-generator	50	75	
Total KW	1,300	1,825	1,825

The clean ballast system will be capable of deballasting the vessel in approximately 10 hours in normal operating conditions. The system will include one steam turbine driven main ballast pump and one ballast stripping eductor.

4.2.5 Accommodation and Navigation Spaces

A crew of 27, plus pilot will be accommodated in a five level after house on the 60,000 DWT vessel and in a six level house on the larger vessels. The proposed arrangement of the six level house is shown in Dwg. No. 7330-108, Sheets 1 through 3. The proposed complement, based on current standards for geared steam turbine propulsion systems with centralized control, will include the following personnel:

Deck Dept.	Engine Dept.	Steward's Dept.
1 - Master	1 - Chief Engineer	1 - Steward/Cook
1 - Radio Operator	3 - Ass't. Engrs.	1 - Cook/Baker
3 - Mates	3 - Q.M.E.D.*	3 - Messmen
6 - A.B. Seamen	1 - Wiper	
3 - Ordinary Seamen		
14 Total	8 Total	5 Total

* "Qualified Member of the Engine Department"

Total Complement	27
Pilot	1
Spare	1
Total accommodation	29

Accommodations, including one pilot's cabin and one spare cabin, will be provided in single berth cabins. Unlicensed personnel quarters will be equipped with semi-private and licensed personnel with private toilet and shower. All accommodations, messing, lounge, recreation, and navigation spaces will be air conditioned.

4.2.6 Structural Design

Structural designs of the three vessels were carried out in sufficient detail to provide a basis for weight and cost estimation and to identify problem areas requiring further study or development. The sequence of tasks included preparation of loading studies, computation of bending moments, selection of required section modulus, and preparation of structural midship section drawings. The latter, described in the following sections, were used as the basis for preparation of steel weight estimates.

Structural designs were developed to meet the 1973 Rules for Building and Classing Steel Vessels of the American Bureau of Shipping, Reference 5. Personnel of the American Bureau of Shipping provided assistance in evaluating the preliminary designs and their recommendations were incorporated into the design where appropriate. However, this limited review of the designs does not constitute approval by A.B.S. of the structural design concepts or details.

The use of conventional mild steel was assumed for all designs. In later design stages for a particular service, optimization studies would be conducted to evaluate the merit of selective use of high strength steels, particularly for the deck structure.

Quantitative information relative to design criteria and requirements is summarized in Table 9. Further discussion regarding the structural designs is included with the individual ship descriptions following.

4.2.7 Stability

An inherent characteristic of the restricted draft form is the very high value of initial metacentric height, GM, at all conditions of loading. A summary of limiting values of

GM for the three designs is given in Table 10. These are well beyond normal GM values; unusually short roll periods, with corresponding high roll accelerations, will be experienced. A compensating factor which may modify this condition is the high roll damping characteristic of the high B/T form. Further, because of the short roll periods, such vessels may not couple with long swells and motion could be moderate under such conditions.

Floodable length calculations were prepared for the three designs and are included in the report as Figures 15, 16, and 17. In all cases, a one-compartment flooding standard is obtained with ample margin. A limited damaged stability study indicated that all designs will also meet a one-compartment damage standard.

Calculations were made to determine maximum grain heeling moments for the 60,000 DWT single hatch design, in accordance with methods given in the U. S. Coast Guard Navigation and Vessel Inspection Circular No. 1069, the 1969 Equivalent to Subchapter M, Reference 6. Tables of allowable heeling moments and volumetric heeling moment tables were prepared for various grain loading conditions. It was determined that with one hold completely slack at maximum waterplane level, the maximum volumetric heeling moment was well below the allowable heeling moment at the applicable virtual center of gravity.

Due to the longitudinal bulkhead arrangement of the 125,000 DWT and 200,000 DWT twin hatch designs, the relative magnitude of the maximum volumetric heeling moments for these designs was determined to be much less than that of the single hatch ship; consequently, these designs would have a relatively smaller reduction in GM due to grain shifts.

4.2.8 Speed and Power

Speed and power estimates for the three designs were based on the following data and assumptions:

a. Residuary resistance was estimated from an extrapolation of Taylor's Standard Series, Reference 7, modified by empirical corrections derived from available proprietary test and trial data. In general, the residuary resistance is expected to be less than that predicted by a direct extrapolation of Taylor's Series.

b. Frictional resistance was based on the I.T.T.C. formulation, with $\Delta C_f = 0.00015$.

c. EHP was increased 2% for appendages.

d. Propeller data was obtained from the Troost "B" series charts.

Propeller characteristics selected for the three designs are tabulated below:

Design	60,000 DWT	125,000 DWT	200,000 DWT
Diameter	21' - 0"	25'-2-1/2"	30' - 0"
Pitch/diameter	0.87	0.89	0.69
RPM @ 80% max SHP	80	90	100

Predicted speed-power curves are given in Figures 18 and 19.

4.3 Design Description, 60,000 DWT Bulk Carrier

4.3.1 Arrangement

The general arrangement of the 60,000 DWT design is shown in the Outline Arrangement Drawing No. 7330-103. Except for the unusual proportions, the vessel is conventional in arrangement. Cargo holds are arranged with 30° upper sloping wing bulkheads, 45° lower sloping wing bulkheads, single skin side shell, and an inner bottom. Wing tank and double bottom spaces are piped for clean ballast service. Hold volumes are adequate to carry full deadweight cargoes of about 47 cu ft/ton cargo for 5,000 mile boyages. In the event that grain cargoes of lower density are carried, the upper wing tanks could be fitted with grain hatches on the upper deck and means for dumping into the main hold through openings in the upper sloping wing bulkhead.

Cargo, fuel, and ballast capacities and centers are summarized in Tables 11 and 12.

4.3.2 Structural Design and Arrangement

Limiting loading conditions were computed for a range of cargoes and ballast loadings, for 5,000 and 10,000 mile voyages. The results are summarized in Table 13. For homogeneous loading, essentially even keel departure can be obtained for 5,000 mile voyages. The homogeneous cargo stowage factor is 46.5 to 47 cu ft/ton voyages of 5,000 to 10,000 miles.

Heavy and light ore loadings are shown for stowage in alternate holds. The attempt was made to select loadings which resulted in the highest cargo center of gravity, while obtaining acceptable values of bending moment and shear stress.

Ballast loadings indicate that a clean ballast capability of about 40% DWT can be obtained without using peak tanks.

Structural design information is included in Table 9. The structural arrangement through cargo holds and in way of a typical transverse bulkhead is shown in the Midship Section and Transverse Bulkhead, Drawing No. 7330-102. The cargo section is arranged with longitudinal framing in the deck and bottom structure and transverse framing in the side shell. The upper sloping wing bulkheads are also transversely framed to permit free flow of grain in the event the upper wings are modified to carry light grains.

The transverse bulkhead is of the vertically fluted type. The bulkheads are joined to sloping stools at the bottom to reduce the bulkhead span, and to provide for ease of removal of bulk cargoes. The bulkheads are fitted with sloping transverse shedder plates to reduce span of the flutes while minimizing volumetric losses.

4.3.3 Cargo Handling

No cargo handling gear will be provided.

Automatic hatch covers of fore and aft rolling type will be fitted to hatches 2 through 9. The covers will be of the "piggy-back" arrangement, as supplied by Mac Gregor-Comarain, Inc. The covers work in pairs at each hatch, with one panel being raised by hydraulic jacks, permitting the motorized second panel to roll underneath. The raised panel can then be stacked on the motorized panel which can roll the two covers into any position over the hatchway. Operating gear will consist of a rack and pinion drive including motor-driven vertical axis pinions which mate with racks fitted to the underside of the covers.

The cover over number 1 hatch will be of the hydraulically operated folding type with two leaves.

4.3.4 Rudder and Steering Gear

To insure an acceptable level of directional stability and good maneuvering capability, unusually large rudders have been adopted for the series. For the 60,000 DWT design, a spade rudder with approximately 2.8% of underwater profile lateral area is shown on the arrangement plan.

Steering gear will be of the dual, electro-hydraulic type, capable of moving the rudder to 35° port and starboard.

4.4 Design Description, 125,000 DWT Bulk Carrier

4.4.1 Arrangement

The general arrangement of the 125,000 DWT design is shown in the Outline Arrangement Plan, Drawing No. 7330-203. The profile arrangement is similar to that of the 60,000 DWT design except for the six level house aft and provision of a forward ballast deep tank.

Because of the unusually large breadth, a twin hatch arrangement was adopted. This configuration provides for good access to the holds while providing for upper wing ballast tanks of reasonable dimensions. In addition, the hatch covers will be of moderate size, consistent with available equipment. The twin hatch arrangement incorporates a continuous longitudinal centerline deck and box girder in association with a non-tight longitudinal bulkhead. The latter provides support for the deck structure and effectively divides the grain waterplane area to reduce grain stability requirements. The lower portion of the longitudinal bulkhead is fitted to a sloping stool structure at the inner bottom. This arrangement reduces the bulkhead span, effectively joins the bulkhead to the double bottom structure and provides for appropriate geometry for ease of cargo removal. Access openings at the forward and after ends of the longitudinal bulkhead stool will be provided in each hold to permit passage of a small bulldozer for cleaning operations and to insure athwartship free flooding of the cargo holds.

Cargo, fuel and ballast capacities are summarized in Tables 14 and 15.

4.4.2 Structural Design and Arrangement

Loading studies were prepared for a range of cargoes and ballast loadings, for 5,000 and 10,000 mile voyages. The results are summarized in Table 16. Since the concept design deadweight was somewhat greater than anticipated, because of changes in displacement and light ship weight relative to the computer design, the resulting homogeneous cargo stowage factor is about 45.5 to 46 cu ft/ton. This value could be increased significantly for light grains by providing for carriage of grain in the upper wing tanks.

Heavy and light ore loadings are shown for stowage in alternate holds. As in the previous design, loadings were selected to minimize initial stability, within the limits of acceptable bending moment and shear stress.

The ballast arrangement indicates a 54% ratio of ballast to deadweight, by providing for carriage of water ballast in number 3 cargo hold. In a design modification, it would be possible to eliminate this particular ballasting requirement by providing for water ballast capacity in the lower stool spaces of the transverse and longitudinal bulkheads. In each case, those spaces would be combined with the adjacent double bottom tanks. Use of the hold for ballast, however, effectively raises the ballast center and reduces the high initial stability.

Structural design information is included in Table 9. The structural arrangement through a typical cargo hold and in way of the transverse and longitudinal bulkheads is shown in the drawing Midship Section and Transverse Bulkhead, Drawing No. 7330-202.

Effective longitudinal material is provided in the deck structure, side shell, and bottom structure. The longitudinal bulkhead, including the lower stool, was assumed to be ineffective.

For the design of the longitudinal bulkhead, a vertically fluted configuration was adopted in order to minimize loss of cubic capacity. The bulkhead was designed to resist a static load on one side of ore at 12 cu ft/ton, stowed to the upper deck level, with the vessel heeled to 30°. The bulkhead is reinforced by longitudinal shedder plates, in the manner normally adopted for the transverse bulkheads.

It should be noted that optimization of structural design was beyond the scope of this study. In a more comprehensive study, other longitudinal bulkhead configurations, including a double plate configuration with all stiffening within the double plate space, would be considered.

The transverse bulkhead is also of the vertically fluted type, as described for the 60,000 DWT bulk carrier.

4.4.3 Cargo Handling

No cargo handling gear will be provided.

Hatch covers fitted to holds 2 through 9, port and starboard, will be of the fore-and-aft rolling, piggy-back type, as described for the 60,000 DWT design. Covers for number 1 hold will be of the two leave, hydraulic folding type.

4.4.4 Rudder and Steering Gear

A horn type semi-balanced rudder will be provided. To insure an acceptable level of directional stability and maneuverability, a rudder and horn profile area of about 2.8% of the underwater profile area, as indicated on the arrangement plan, would be provided.

Steering gear will be of the dual, electro-hydraulic type, capable of moving the rudder to 35° port and starboard.

4.5 Design Description, 200,000 DWT Bulk Carrier

4.5.1 Arrangement

The general arrangement of the 200,000 DWT design is shown in the Outline Arrangement Plan, Drawing No. 7330-303. The arrangement is similar to that of the 125,000 DWT design. The primary difference is in the larger size and in the lower value of L/B and B/D. The description of the 125,000 DWT design is generally applicable. Capacities are summarized in Tables 17 and 18.

4.5.2 Structural Design and Arrangement

Loading studies were prepared, as for the previous designs, and are summarized in Table 19. As in the case of the 125,000 DWT design it was necessary to provide for ballasting in number 4 hold to obtain an acceptable ballast loading. Again, this arrangement could be eliminated by providing for ballasting in the stool spaces.

Structural design information is summarized in Table '9. Structural arrangement though a typical cargo hold and in way of the transverse and longitudinal bulkheads is shown on the drawing Midship Section and Transverse Bulkhead, Drawing No. 7330-302.

The discussion in Section 4.4.2 regarding the 125,000 DWT design is applicable to this design.

4.5.3 Cargo Handling

No cargo handling gear will be provided. Hatch covers will be provided, as described in Section 4.4.3.

4.5.4 Rudder and Steering Gear

The 200,000 DWT design is proportionately the shortest of the design concepts, with L/B = 5.0. In addition, the hull form is the fullest of the series, with C_B = 0.83. Accordingly, it is likely that directional stability and maneuverability requirements will necessitate fitting of an unusually large rudder. For this design, a horn type semi-balanced rudder of 3.0% of the underwater profile area is proposed.

5.0 CAPITAL COST AND DESIGN ANALYSIS

5.1 Concept Design Cost Estimates

Capital cost estimates of the three concept designs were prepared using the same formulae and constants assumed for the computer design cost estimates. The cost estimating methods differed from the computer design estimates in that actual cost quotations for hatch covers were used instead of the modified Dart values and cost of the electric plant was computed for a realistic estimate of power requirements, rather than the more approximate estimates obtained from the computer program. Both are significant cost items since base electric plant costs are approximately $1,000,000. and current hatch cover costs are about $800,000 for the 60,000 DWT design and about $1,800,000 for the 200,000 DWT design.

Summaries of the capital cost estimates are given in Table 20. The base costs are direct computations from the Dart formulations, modified and escalated as shown in Appendix B.

5.2 Comparison with Computer Designs

Characteristics and costs of the computer and concept designs are compared in Table 21. As noted earlier, relative to the concept designs, the computer design program tended to overestimate weights and underestimate cargo cubic capacity of the restricted draft forms, for a given hull form geometry. The net effect was the requirement for increasing depth of the computer design hulls and the estimation of less light ship weight and corresponding greater deadweight of the concept designs. Since capital cost estimates are primarily based on weights, the concept design costs are below the corresponding computer estimates.

The steel weight estimate discrepancy is greatest for the conventional geometry of the 60,000 DWT design wherein the concept design steel weight is about 800 tons, or about 6%, below the computer estimate. For the 125,000 DWT design, the weight reduction is only about 2%. In this case, the twin hatch configuration is considerably heavier, because of the existence of the longitudinal centerline bulkhead and associated deck and bottom structure, and the weight reduction in favor of the concept design is only about 2%. For the 200,000 DWT design, the steel weight estimates favor the computer design by about 3%. In this case, the ratio of L/D is very low, indicating a hull of unusual depth. The additional weight of the longitudinal bulkhead system is even greater and represents a significant portion of the weight of the cargo section.

Outfit weights of the two largest computer designs considerably exceed the corresponding concept design estimates. This is primarily because of the lower unit weights of the comparatively small hatch covers in the twin hatch arrangements, compared to the very high weights predicted by the computer for the single hatch arrangements.

The cost ratios in Table 21 follow predicted patterns in that costs/DWT decrease with ship size. In each case, cost/DWT is less for the concept design relative to the computer design. This latter comparison is not quite equitable since the displacements of the concept design hull forms tended to be slightly greater than corresponding values of the computer designs.

Tabulated values of cost/light ship were computed for light ship excluding margin since no cost value was assigned to the margin in either case. It should be noted that the cost formulations used result in a lower cost/ton, particularly for steel, as component weight increases.

Comparisons with costs of bulk carriers of conventional proportions and of the same deadweight are included in the following section of this report.

6.0 CONVENTIONAL AND RESTRICTED DRAFT DESIGN AND COST COMPARISON

The computer design program was used to prepare design and cost data for conventional 60,000 DWT, 125,000 DWT and 200,000 DWT dry bulk carriers. Representative drafts for the conventional vessels were selected from an inspection of Figure 1 and a series of designs was developed for a range of values of LBP and C_B. The designs selected for comparison are near optimum with respect to costs, while retaining characteristics within the range of current practice.

Characteristics and costs of restricted draft and conventional 60,000 DWT, 125,000 DWT and 200,000 DWT designs are compared in Tables 22, 23, and 24, respectively. Principal characteristics, capital costs and a range of RFR values are tabulated for computer and concept designs of restricted draft vessels and the computer designs of the conventional deep draft vessels. Corresponding supporting data is summarized in Tables 25, 26, and 27; productivity data, in terms of ton/miles/yr, is given in Tables 28, 29 and 30.

As noted in the discussions in Section 5.0, the computer program tends to be conservative in the design of restricted draft vessels. In addition, program and concept design differences with respect to hatch covers and electric plants were noted. Further, deadweight capacities of the restricted draft concept designs are from 1% to 3% greater than the corresponding computer designs. Accordingly, comparisons of the tabulated design characteristics and costs should be made with caution.

In general, low values of L/B and L/D, within conventional limits, tend to favor low initial costs. The ratios L/B, L/D and B/T are not independent, however, and extreme or unusual values indicating unusual ship proportions may adversely affect steel weights and corresponding costs.

6.1 Capital Costs

For the 60,000 DWT designs the comparison in Table 22 indicates a higher value of L/B and lower values of the ratios L/D and B/T for the 40 ft draft design. The value of $C_{DW} = DWT/\Delta$, a simple measure of overall design efficiency, favors the deeper draft design. The cost comparison is less clear, for the reasons noted above. On the basis of cost/DWT, the 40 ft design is slightly less costly than the concept design. RFR values are virtually identical, reflecting the slightly greater productivity of the concept design.

The comparison of the 125,000 DWT designs in Table 23 follows a similar pattern. The deeper draft design is more "efficient", with respect to the coefficient C_{DW}, and capital costs are slightly lower than corresponding values for the concept design. It should also be noted that the computer design reflects the single hatch configurations, with an inherently lower value of steel weight and correspondingly higher values of hatch cover weight, relative to the twin hatch design. RFR values of the deeper draft vessel are about 3% to 4% below corresponding values for the concept design.

The comparison in Table 24 for the 200,000 DWT designs is of particular interest. It will be recalled that the 200,000 DWT design represents a compromise selection and is well below the maximum feasible deadweight capacity for 55 ft draft. The value of L/B = 5.0 is the minimum accepted for the study and L/D is low at a value of 11.98 for the computer design and 11.55 for the concept design. The 63 ft conventional draft design was chosen to have the same values of LBP and C_B as the 55 ft draft designs. The resulting values of L/B = 5.895 and L/D = 10.711 are close to the minimum for existing vessels. The comparison indicates a more favorable C_{DW} value for the deep draft vessel, but a small increase in cost/DWT, relative to the concept design values. This result reflects major differences such as hatch cover costs and weights rather than the apparent "efficiency" of the deep draft design. RFR values favor the restricted draft concept design by about 1.5% to 2.0%.

6.2 Operating Costs

Annual operating costs of restricted draft and conventional designs are best compared by examining the second and third columns of Tables 25, 26 and 27, corresponding to data for the concept design of the restricted draft vessel and computer design of the equivalent conventional, deep draft, vessel.

Relative to the conventional designs, total operation and support costs, excluding fuel costs, are slightly higher for the restricted draft vessels, about 1-1/2% to 3-1/2% for the three values of deadweight. Manning and subsistence costs are a function of crew size only and are constant for the series. Stores and supplies costs vary with shaft horsepower and deadweight, hence vary only slightly for a given deadweight. Maintenance and repair costs are computed as a function of cubic number, L × B × D/100, and are about 5% to 6% higher for the restricted draft designs. H and M insurance costs vary directly with investment cost and deadweight, hence will favor the conventional design, except for the case of the 200,000 DWT designs. P and I insurance, a function of cubic number and number of crew, follows the same trend as maintenance and repair costs, varying from about 6% to 8% higher for the restricted draft designs.

For a given voyage length, utilization and cargo handling rate, fuel consumption and corresponding costs is a simple function of required horsepower. Tabulated differences in fuel costs correspond directly to the differences in estimated horsepower requirements.

6.3 Constant Draft Comparisons

The primary objective of this study is the development of restricted draft designs for three given drafts. Vessels were selected on the basis of minimum RFR, subject to the requirement for development of restricted draft concepts well beyond state of the art. Accordingly, the preceding discussions were based on constant deadweight comparisons of restricted draft and deep draft designs.

Constant draft comparisons, i.e., the variation of deadweight capacity with change in dimensions and proportions, are shown in the basic computer results plotted in Figures 2 through 13. Figure 20, obtained from these earlier plots, is a composite summary of RFR versus deadweight for the three constant draft studies. The values plotted are the lowest RFR points for a constant 16 knot service speed and for the cargo handling rate, utilization, and voyage length indicated. The deep draft computer design points are also indicated. Note that the deep draft designs are for service speeds of 15 knots at 60,000 DWT and 200,000 DWT.

The curve plotted on Figure 20 has the expected characteristic of decreasing RFR with increasing deadweight. However, the curve reaches a minimum RFR at the comparatively low value of about 175,000 DWT, at 55 ft draft. It is expected that RFR values for conventional deep draft vessels would reach a minimum RFR at significantly higher values of deadweight. Such trends are shown graphically for tank vessels in Reference 1.

7.0 PROBLEM AREAS

During the course of the study, several technical problem areas were identified and the need for additional research and development, beyond the current effort, was recognized. None of the problem areas is expected to be a barrier to design, construction, or operation of restricted draft vessels. This is clearly the case with respect to tank vessels, since several large vessels of this type are under construction, as reported in Reference 8.

7.1 Resistance and Propulsion

Predictions of speed and power for unusual forms are less reliable than corresponding predictions for conventional hulls. Standard series data as well as published and proprietary individual ship model test and trial data is generally available to the designer. For the current study, predictions were made from extrapolations of standard series data, modified by consideration of certain published and proprietary information on full form designs. The preparation of restricted draft designs should include appropriate model test studies. In any case, the limited published data pertinent to restricted draft forms, such as Reference 8, does not indicate that expected power requirements will significantly differ from conventional ship form powering levels.

7.2 Directional Stability and Maneuvering

There is some evidence to indicate that full form, low L/B hull forms will exhibit less than satisfactory directional stability characteristics, and requirements for unusually large rudders and steering gear may be indicated. These characteristics are predictable from model tests which would be conducted in association with the resistance and propulsion work discussed above. This is of particular importance with the current concern for ship safety and associated pollution control considerations.

Practical solutions to the potential problems are indicated in Reference 8 wherein extensive tests of large scale manned models were conducted to determine maneuvering and control characteristics. For the particular cases of a series of

300,000 DWT and 400,000 DWT restricted draft tankers under construction in Japan, unusually large rudders will be fitted, with corresponding requirements for oversize steering gear and reinforced stern structure.

It is likely that some future restricted draft designs will be built with twin screw propulsion and twin rudders to satisfy both propulsion and control requirements. Existing conventional tank vessels such as the 106,000 DWT U. S. flag MANHATTAN and the 320,000 DWT UNIVERSE KUWAIT class are so constructed. Relative to single screw, single rudder, arrangements, this represents a significant cost increase which may be justified for particular trade situations.

7.3 Seakeeping

The seakeeping characteristics of the proposed restricted draft hull forms can only be estimated at this time. With respect to slamming and potential bow damage in heavy seas, some reported experience tends to indicate that the cylindrical bow forms adopted for this study perform satisfactorily. With respect to roll motion, the extremely high values of GM indicate that short roll periods and high roll accelerations will be experienced under many conditions. There is some indication that the roll characteristics of the high GM form will not couple with long swells, and motion in such an environment may be reasonable.

Methods of minimizing roll motions will be limited to cargo and ballast loading arrangements to obtain high values of center of gravity and the fitting of large bilge keels to provide roll damping. For dry bulk carrier service, roll stabilization systems of reasonable size will not be effective for the expected conditions of high initial stability. In any case, analytical predictions of roll characteristics and corresponding model test verification is clearly indicated for early restricted draft designs.

7.4 Structural Design

Certain potential problem areas and the corresponding need for specific studies were identified during the study. These include:

7.4.1 Applicability of A.B.S. and other existing regulatory requirements to ships of high B/D form. Existing A.B.S rules, for example do not apply to vessels with B/D > 2.0.

7.4.2 High strength steel versus mild steel construction should be evaluated for both single and twin hatch arrangements. The design studies were limited to consideration of mild steel construction only.

7.4.3 Longitudinal bulkhead configurations other than the vertically fluted type should be considered. A double plate configuration appears attractive and should be evaluated with respect to cargo and ballast capacity and cost. Junction of longitudinal and transverse bulkheads should be studied carefully.

7.4.4 Required depth of innerbottom as determined from existing rules should be studied independently by techniques such as grillage analysis.

7.5 Cargo Handling

Proportions of restricted draft vessels, as proposed in this study, will be characteristically of low L/B for given deadweight. Hull breadths may exceed the outreach capability of some existing terminal facilities, particularly in the case of the larger twin hatch designs. Accordingly, the development of future restricted draft bulk carrier systems will include corresponding consideration of cargo handling facilities and ship loading procedures.

7.6 Construction and Drydocking Facilities

Each of the three proposed designs could be built at one or more existing or proposed construction facilities in the United States. For the larger vessels, availability of drydocking facilities will be limited for the near future.

7.7 Pollution Control Considerations

Except for the consideration of stability and control, as discussed earlier, no particular disadvantage is foreseen with respect to pollution control. The situation will require further consideration for restricted draft combination carriers such as ore-bulk-oil (OBO) and ore-oil carriers.

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GLOSSARY

Block Coefficient, C_B	Ratio of the underwater volume under a given waterline to the volume of a rectangular solid with dimensions equal to waterline length, waterline depth and mean draft of the vessel.
Deadweight	Total ship carrying capacity including cargo, fuel crew and effects, stores, ballast and miscellaneous consumables.
Displacement	Weight of water displaced by ship's hull; sum of light ship weight and deadweight.
Draft, Freeboard	Depth below the waterline to the lowest point of the hull, where the waterline is the maximum allowable according to the applicable Loadline Regulations.
Draft, Scantling	Maximum operating draft permitted according to structural limitations, as determined by applicable rules of a classification society or regulatory agency; generally less than freeboard draft.
Draft, Service	Normal design or operating draft; may be less than freeboard or scantling drafts.
Effective horsepower, EHP	Power necessary to overcome the resistance of a ship at a given speed.
Floodable Length	The length of a ship which may be flooded without sinking below the margin line (generally assumed to be a line 3 inches below the deck). Floodable length varies along the ship's length and is usually greatest amidship.

Freeboard	Vertical distance from the waterline to the freeboard deck at side.
Light Ship Weight	Weight of the ship complete with all steel, outfit and machinery, including normal operating liquids in the machinery; excludes all items of deadweight.
Metacenter, M	For a small angle of heel, the intersection of a vertical line through the center of buoyancy with the centerline plane is termed the metacenter, M.
Metacentric Height, GM	Distance from the metacenter to the center of gravity of the ship. The value of GM is a measure of initial intact stability.
Stability, Damaged	Tendency of a vessel to remain upright or in an equilibrium condition, when in a damaged and flooded condition.
Stability, Intact	Tendency of a vessel to remain upright, or to return to the upright condition when heeled due to action of wind, waves or asymmetrical loading.

APPENDIX A

CONCEPT DESIGN COMPUTER PROGRAM

The concept design computer program used for these studies was developed by HYDRONAUTICS, Incorporated for the design of dry and liquid bulk carriers, including tank vessels, dry bulk and ore carriers and combination carriers such as ore/oil and ore/bulk/oil (OBO) carriers. For each of these ship types it is possible to vary a range of parameters, including deadweight, limiting dimensions, proportions, speed, internal arrangement, machinery type, fuel rate, and number of crew. The output of these programs is a summary description of the technical characteristics of a feasible ship, construction and operating costs, life cycle costs, and required freight rate under a range of conditions. This program is presently being run on the HYDRONAUTICS, Incorporated IBM 1130 Computer which has a 10,000-word core and magnetic disk storage.

The program logic, shown diagrammatically in Figure A-1, is based on the usual iterative ship design technique. The computer design process begins with a displacement derived from the assumed initial input dimensions and block coefficient C_B. Each successive iteration begins with a corrected displacement, and the corresponding corrected values for the variable basic dimensions which exist near the beginning of each iteration are used in the powering estimates. The latter are based on data from Reference 7 and propeller characteristics from Troost B-Series propeller data. This is followed by detailed calculations of the available volumes and of steel, machinery, and outfit weights. At the end of each cycle, the resulting deadweight is obtained and compared with the target value. In addition, trim is checked and cargo LCG adjustments for the next iteration are prepared. The next iteration begins with a corrected displacement. The final iteration is obtained when the target deadweight has been achieved. For the final iteration, transverse stability and cost calculations are made.

The program has been written as a working tool for the practicing naval architect. Optimization routines which search and identify the optimum vessel for a given economic criterion were deliberately excluded from the program in order to use the maximum computer capacity for technical definition of ship characteristics and to provide for maximum flexibility in selection of input variables. For a given set of input parameters, optimization is readily accomplished by simple inspection of the output cost data such as capital cost, required freight rate, and life cycle cost per ton-mile.

The program can accept as input the following operator's primary requirements and secondary variables:

1. Ship type, including dry or liquid bulk and combination bulk carriers.

2. Arrangement; e.g., number of cargo tanks, extent of superstructure, single versus double skin side shell for dry bulk and OBO carriers, assignment of upper sloping wing tanks to ballast and/or cargo service.

3. Cargo requirements, including deadweight, stowage factor, heating coil requirements.

4. Operational constraints including service speed, draft and trim restrictions, cruising range, voyage characteristics (distance, port time), utilization factors (i.e., percent of service time carrying cargo versus ballast).

5. Geometry, including form coefficients (fixed or input parametrically), dimensional constraints, proportions.

6. Propulsion, including single versus twin screw, service margin, type of propulsion plant, fuel rate.

7. Light weight basis, including selective effects of high strength steels and tank coating systems.

8. Cost constants, including interest rates, investment cost constants for each weight summary.

A sample output sheet is reproduced here as Table A-1. This particular example was the basis for selection of characteristics of the 60,000 DWT/35 ft draft bulk carrier design developed in this study.

The first page of the output contains the primary description of ship characteristics. Certain of the characteristics will be recognized as input requirements; e.g., service speed, cargo deadweight, and stowage factor.

Investment costs for each of three, five, and ten ships are given on the second page, using learning curve and weight group cost data. Operating costs are calculated, and these values are combined with investment costs in an appropriate manner to obtain required freight rates and life cycle cost/ton-mile, as a function of number of ships in series production, voyage length and utilization. Cost constants assumed in the program may be readily changed to suit a specific operator's requirements.

The second page also contains weight summaries of the various groups composing the total light ship weight. The importance of developing the most reliable weight estimating program possible, within the limits of a computer program, was recognized early in the program development. Such information is fundamental to the definition of ship characteristics and provides the basis for investment cost estimating. A considerable amount of available detailed weight data was compiled into functional groupings of smaller MARAD weight groups to serve as the basis for the weight estimating procedures. Steel weights, for example, are estimated separately for cargo section, ends, and superstructure. Longitudinal steel weights are estimated independently and reflect approximate section modulus requirements of the American Bureau of Shipping.

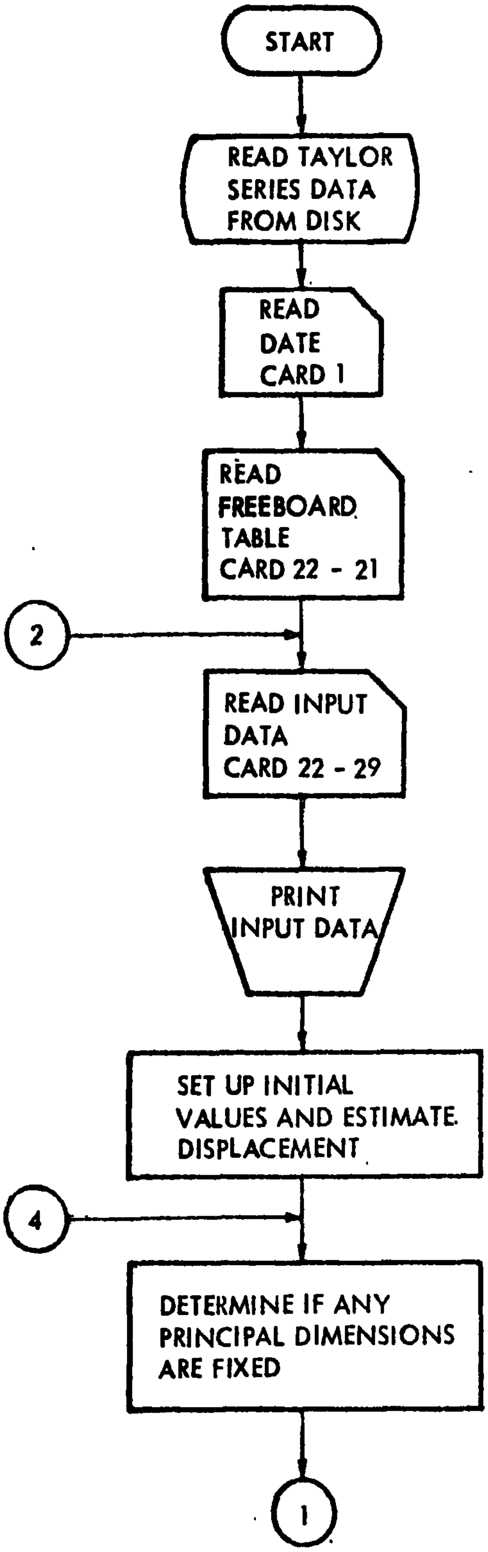


FIGURE A-I - FLOW DIAGRAM FOR HYDRONAUTICS, INCORPORATED PROGRAM FOR BULK CARRIER AND TANKER CONCEPT DESIGN

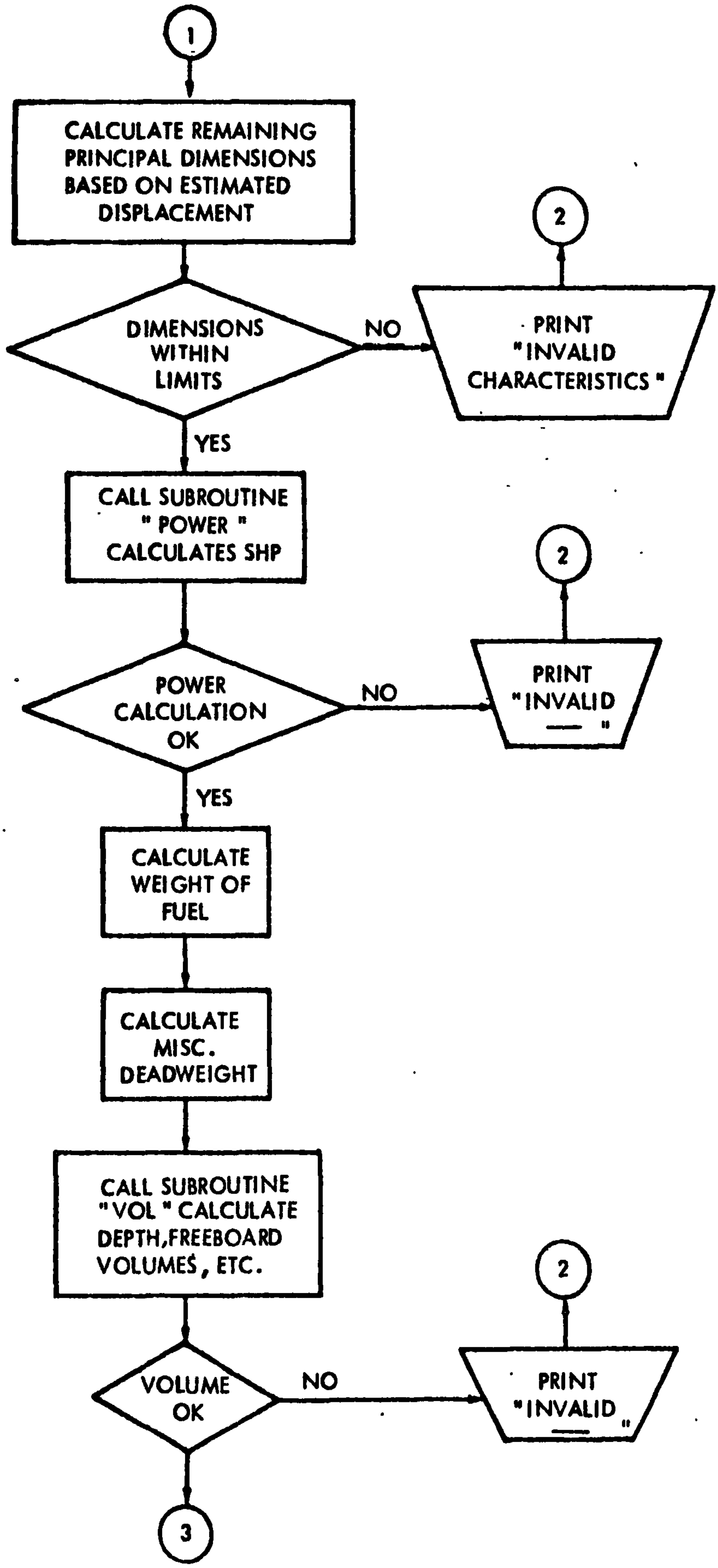


FIGURE A-1 - CONTINUED

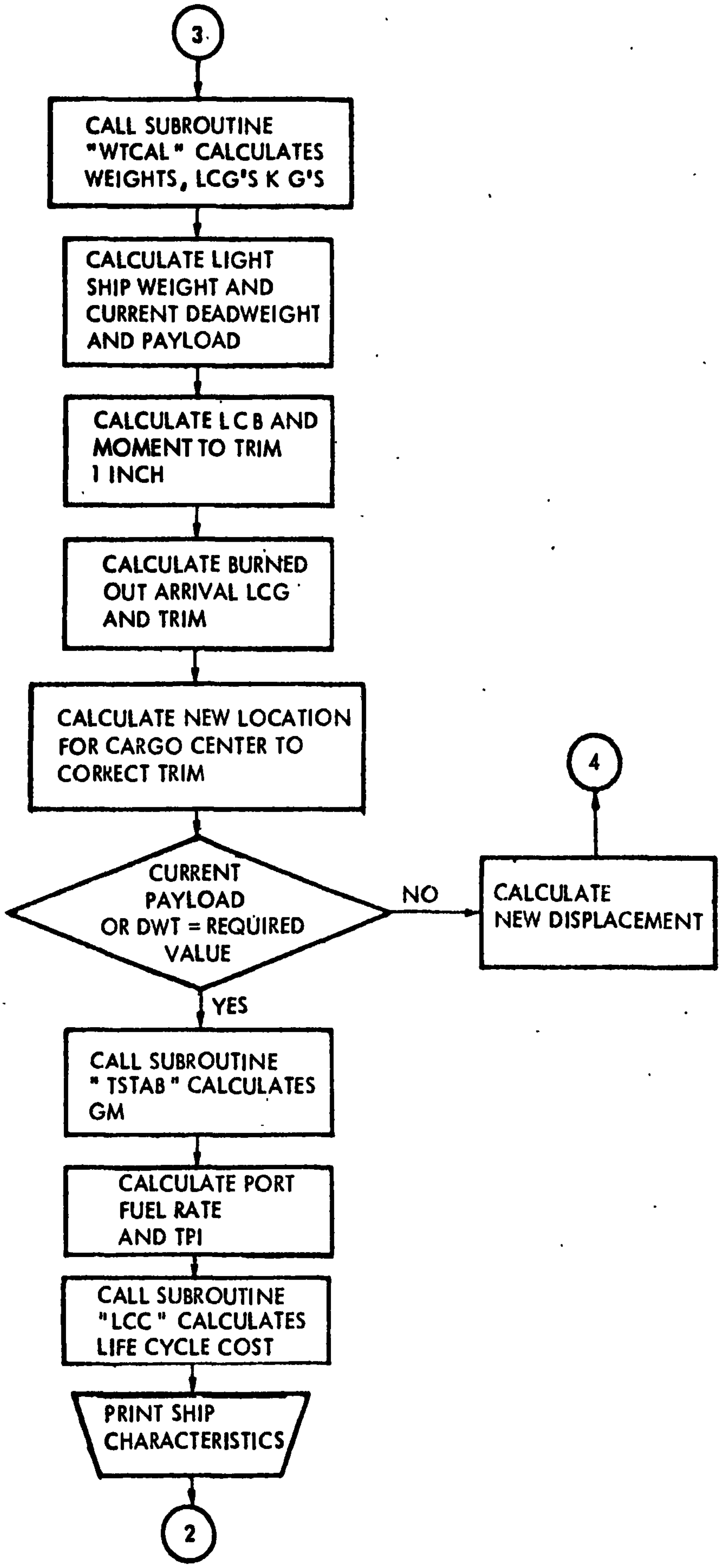


FIGURE A-1 - CONCLUDED

TABLE A-1

PRELIMINARY CHARACTERISTICS OF 1/31/73 PROPOSED FOR T=35'

BULK CARRIER

PRINCIPAL CHARACTERISTICS

LENGTH B. P.	=	740.00 FT.	MACHINERY TYPE -		STEAM TURBINE
			SHP, MAX CONTIN.	=	14608.25
BREADTH, MOLDED	=	131.11 FT.	SERVICE SPEED	=	15.00 KNOTS
DEPTH, MOLDED	=	51.99 FT.	CLEAN BALLAST CAPACITY	=	31057.05 TONS
DRAFT, DESIGN	=	35.00 FT.	CARGO CAPACITY HOLDS	=	2946012.0 FT3.
TOTAL DEADWEIGHT	=	60000.00 TONS	TOTAL DWT AT FREEBOARD DRAFT	=	67017.0 TONS
CARGO DEADWEIGHT	=	58587.41 TONS	RANGE	=	5000.0 MILES
TOTAL DISPLACEMENT	=	76649.31 TONS	FUEL RATE (SEA)	=	3.13 TONS/HOUR
TPI	=	200.89 TONS	FUEL RATE (PORT)	=	0.62 TONS/HOUR
MTI	=	10041.05 FT. TONS	NUMBER OF HOLDS	=	0

WEIGHT DATA

ITEM	WEIGHT	KG	LCG
TOTAL STEEL	13445.79	28.11	-6.89
OUTFIT	1960.43	50.14	-16.23
MACHINERY	763.31	25.92	-287.93
MARGIN	485.08		
LIGHT SHIP	16654.64	30.68	-21.29
FUEL	1178.56	20.79	-283.71
CARGO	58587.41	28.66	34.42
MISC. DWT.	228.69	44.19	-292.11
TOTAL DWT	60000.00	28.56	
TOT. DISPL.	76649.31	28.83	

LENGTH AND VOLUME SUMMARY

	FORE PEAK	DEEP TANK	CARGO	DEEP TANK	PUMP RM	ENG. RM	AFT PEAK
LENGTH	37.0	1.7	589.9	0.0	0.0	83.5	27.7
VOLUME	57135.9	5577.7	3916149.5	0.0	0.0	265133.3	16984.6

FORM PARAMETERS

CB	=	0.790	L/B	=	5.643
CP	=	0.793	L/D	=	14.232
CX	=	0.995	B/H	=	3.746

POWERING DATA

NUMBER OF PROPS	=	1.	RPM	=	80.00
EHP	=	8732.5	P/D	=	0.843
PC	=	0.717	BAR	=	0.400
PROP. DIAMETER	=	24.50			

FREEBOARD AND STABILITY DATA

REQUIRED FREEBOARD	=	14.12 FT.	GM UNCORRECTED	=	29.51 FT.
AVAILABLE FREEBOARD	=	16.99 FT.	FREE SURFACE CORRECTIONS	=	0.00 FT.
DISPL. AT FREEBOARD DRAFT	=	83671.7 TONS	GM CORRECTED	=	29.51 FT.

TRIM CHARACTERISTICS

TRIM BY BOW = - TRIM BY STERN = +

BURNED OUT ARRIVAL LCG= 22.09 FULL LOAD DEPARTURE LCG= 16.45

BURNED OUT ARRIVAL TRIM = -38.70 IN. FULL LOAD DEPARTURE TRIM= 4.33 IN

TABLE A-1 (CONCLUDED)

ECONOMIC DATA (REQUIRED FREIGHT RATE)

NUMBER OF SHIPS	INVESTMENT PER SHIP	FIXED COST/ YEAR	FUEL COST/DAY AT SEA	FUEL COST/DAY IN PORT	RFR*1000 FOR ROUND TRIP VOYAGES AT ONE WAY DISTANCES OF 1000.	2000.	5000.	7500.	10000.	15000.
UTILIZATION = 0.500, CARGO HANDLING = 1250.TON/HOUR										
3	11135568.	505288.	1742.	347.	1.0276	0.8315	0.7192	0.6985	0.6912	0.6899
5	10629406.	499781.	1742.	347.	0.9979	0.8083	0.6998	0.6798	0.6727	0.6716
10	10123244.	494274.	1742.	347.	0.9683	0.7851	0.6804	0.6611	0.6543	0.6533
UTILIZATION = 0.666, CARGO HANDLING = 1250.TON/HOUR										
3	11135568.	505288.	1742.	347.	0.8605	0.6685	0.5574	0.5359	0.5273	0.5234
5	10629406.	499781.	1742.	347.	0.8353	0.6496	0.5422	0.5214	0.5132	0.5095
10	10123244.	494274.	1742.	347.	0.8101	0.6308	0.5271	0.5070	0.4991	0.4956
UTILIZATION = 0.500, CARGO HANDLING = 5000.TON/HOUR										
3	11135568.	505288.	1742.	347.	0.7582	0.6968	0.6654	0.6626	0.6642	0.6720
5	10629406.	499781.	1742.	347.	0.7374	0.6780	0.6477	0.6451	0.6467	0.6543
10	10123244.	494274.	1742.	347.	0.7166	0.6593	0.6301	0.6276	0.6291	0.6366
UTILIZATION = 0.666, CARGO HANDLING = 5000.TON/HOUR										
3	11135568.	505288.	1742.	347.	0.5911	0.5338	0.5035	0.4999	0.5004	0.5055
5	10629406.	499781.	1742.	347.	0.5747	0.5194	0.4901	0.4867	0.4872	0.4921
10	10123244.	494274.	1742.	347.	0.5584	0.5050	0.4767	0.4735	0.4739	0.4788

DETAILED WEIGHT DATA

ITEM	WEIGHT
STEEL	
CARGO SECTION	11270.07
ENDS	1774.08
HOUSE	326.20
FOCSLE	75.43
POOP	0.00
TOTAL STEEL	13445.79
OUTFIT	
PASSENGER + CREW OUTFIT	296.36
ELECTRIC PLANT	84.47
STEERING GEAR	20.61
RUDDER	33.88
ANCHORS, CHAINS AND LINES	176.17
DECK MACHINERY	80.17
DECK CRANES	0.00
MISC. FIXED OUTFIT	416.90
HATCH COVERS	785.90
MISC. CARGO OUTFIT	65.94
CARGO PIPING AND MISC. CARGO OUTFIT	0.00
HEATING COILS	0.00
CARGO PUMPS	0.00
TOTAL OUTFIT	1960.43
PROPULSION MACHINERY	
TOTAL MACHINERY,	763.31

APPENDIX B

COST ANALYSIS

Capital Cost

The basic capital cost estimating relationships, obtained primarily from Dart, Reference 3, are summarized in the following tabulation:

Item	Cost, $\$ \times 10^{-6}$
1.0 Steel	
1.0 Cargo section	$0.0004524W + 0.78$
1.2 Ends	$0.0005678W + 0.3968$
1.3 Superstructure 1.4 Houses	$0.000835W + 0.031358$
2.0 Outfit	
2.1 Passenger and crew	$0.00338W + 0.704$
2.2 Cargo	
2.2.1 Hatch covers	$0.0012436W + 0.043$
2.2.2 Miscellaneous	$0.002W$
2.3 Electric plant	$0.00045\ P_{kw} + 0.405$
2.4 Fixed	
2.4.1 Steering gear and rudder	$0.00106W + 0.10163$
2.4.2 Deck machinery	$0.00145W + 0.0178$
2.4.3 Miscellaneous	$0.00503W + 0.161$
3.0 Machinery, (Geared Steam Turbine)	$0.103\ (SHP \times 10^{-3}) + 2.160$

where W = weight in long tons,

P_{kw} = total generator capacity in kilowatts.

The above weight items correspond to the MARAD weight groupings given in the light ship weight summaries in the report.

The above formulations were approximately correct as of January 1970. The values have been escalated and adjusted to a foreign cost basis by the following computation:

$$\text{Adjusted value} = \text{base value} \times 1.18 \times 0.59$$

$$= 0.6962 \times \text{base value}$$

where 1.18 = cost escalation at rate of 1/2% per month, from Jan. 1970 to Jan 1973,

0.59 = conversion factor, U. S. to foreign costs (not adjusted for 1971 - 72 dollar devaluation).

The following unit cost reduction factors for multiple ship production were assumed:

Each of 1 ship	1.00
Each of 3 ships	0.88
Each of 5 ships	0.84
Each of 10 ships	0.80

Productivity

Total port time per voyage was obtained from the following expression:

$$\text{Port time per round trip voyage} = 2\left[\frac{\text{Cargo DWT}}{\text{Cargo rate}}\right] + \text{port delay}$$

where cargo rate = cargo handling rate, assumed to be 1250 tons/hr and 5000 tons/hr in the study,

port delay = 10 hrs per round trip.

The factor 2 is applied to provide for discharge and loading of cargo at each port.

Assumed ship availability for service is 345 days/year, corresponding to 20 days per year out of service for maintenance and repair.

Utilization = % time carrying full cargo; 50% and 66-2/3% values assumed for the study.

Annual Capital Charges = investment cost × 0.11017, corresponding to a 25 year life, no scrap value, sinking fund depreciation and 10% return on investment.

Operating and Support Costs

The following relationships were obtained from Dart, Reference 3, and were modified as shown:

Manpower = $7,500 per man year, reflecting foreign flag operation,

Stores and supplies $/year =

$$1.18(0.828)\left[4500 + \left(\frac{SHP}{3} + 10,000\right) + 0.21\ (DWT + 9500)\right]$$

Subsistence $/year = (1.18)(0.85)($986/man)

Maintenance and repair $/year =

$$1.18(0.60\left[\$90,400 + 0.69\ (CN - 1500) + 0.49\ CN\right]$$

Insurance, H and M, $/year = $0.80\ (I.C.)\ 0.01 + \frac{0.00006\ DWT}{1000}$

Insurance, P and I, $/year = $0.40\ [750\ N_c + 0.61\ CN]$

where 1.18 = cost escalation constant

CN = cubic number

$$= \frac{L \times B \times D}{100}$$

I.C. = Initial investment cost

Voyage Costs

Terminal costs - none

Brokerage and commission costs - none

Fuel costs = \$3.50/bbl

Overhead = \$25,000/year

Cost Criteria

Required Freight Rate, RFR, was chosen as the criterion for design comparisons and selection of optimum designs, where RFR is defined by the expression:

$$\frac{\Sigma \text{ Annual Costs}}{\text{Cargo ton-miles/year}}$$

TABLE 1

Principal Characteristics
Proposed Restricted Draft Dry Bulk Carriers

Item	Near-Minimum RFR	Near-Maximum DWT
Length, B. P.	830'-0"	920'-0"
Breadth, mld.	164'-3"	167'-6"
Depth, mld.	65'-9"	65'-3"
Draft, design, mld.	45'-0"	45'-0"
Displacement, total	140,900 tons	157,500 tons
Light ship weight, about	25,900 tons	32,500 tons
Deadweight, total, about	115,000 tons	125,000 tons
Cargo cubic capacity, 100%, about	5,271,000 cu. ft	5,795,000 cu. ft
Cargo stowage factor, 5,000 mile voyage, about	47 cu. ft/ton	47 cu. ft/ton
Shaft horsepower, A.B.S. max.	22,500	28,500
Service speed (trial speed @ 80% max. SHP, full-load displacement), about	15 knots	16 knots
Complement	27	27
Preliminary form coefficients		
C_B	0.804	0.795
C_p	0.808	0.798
L/B	5.05	5.49
L/D	12.62	14.10
B/T	3.65	3.72

TABLE 2

Cost Data (Ref. Table 1)

Item	115,000 DWT, 15 Knot Bulk Carrier	125,000 DWT, 16 Knot Bulk Carrier
Investment cost, each of five ships	$ 14,588,000	$ 16,935,000
$/DWT	126.85	135.48
Required freight rate, 10,000 mile (one-way) voyage, mils/ton-mile		
Cargo handling rate 1250 tons/hr.		
Utilization 50%	0.5057	0.5220
66 2/3%	0.3910	0.4048
Cargo handling rate 5000 tons/hr.		
Utilization 50%	0.4704	0.4819
66 2/3%	0.3557	0.3648
Required freight rate, 5,000 mile (one-way) voyage, mils/ton-mile		
Cargo handling rate 1250 tons/hr.		
Utilization 50%	0.5489	0.5708
66 2/3%	0.4352	0.4548
Cargo handling rate 5000 tons/hr.		
Utilization 50%	0.4783	0.4907
66 2/3%	0.3646	0.3747

TABLE 3

Principal Characteristics
Proposed Restricted Draft Dry Bulk Carriers

Item	160,000 DWT/16 knots	225,000 DWT/15 knots	200,000 DWT	
			15 knots	16 knots
Length, B.P.	880'-0"	1100'-0"	970'-0"	980'-0"
Breadth, mld.	175'-9"	206'-0"	191'-9"	195'-6"
Depth, mld.	81'-0"	80'-0"	81'-0"	81'-6"
Draft, design, mld.	55'-0"	55'-0"	55'-0"	55'-0"
Displacement, total	191,150	281,500	241,700	243,000
Light ship weight, about	31,150	56,500	41,700	43,000
Deadweight, total, about	160,000	225,000	200,000	200,000
Cargo cubic capacity, 100%, about	7,349,000 cu ft	10,509,000	9,203,000	9,187,000
Cargo stowage factor, 5,000 mile voyage, about	46.7 cu ft/ton	47.4	46.7	46.7
Shaft horsepower ABS, max.	30,000	36,500	32,500	38,000
Service speed (trail speed @ 80% max SHP, full-load displacement), about	16 knots	15	15	16
Preliminary form coefficients				
C_B	0.787	0.790	0.827	0.807
C_p	0.790	0.793	0.831	0.811
L/B	5.01	5.34	5.06	5.01
L/D	10.86	13.75	11.97	12.02
B/T	3.20	3.75	3.49	3.56

TABLE 4

Cost Data (Ref. Table 3)

Item	160,000 DWT/16 knots	225,000 DWT/15 knots	200,000 DWT	
			15 knots	16 knots
Investment cost, each of 5 ships	$17,234,000	$25,559,000	$20,757,000	$21,569,000
$/DWT	107.71	113.60	103.79	107.85
Required freight rate, 10,000 mile (one way) voyage, mils/ton-mile				
Cargo handling rate 1,250 tons/hr.				
Utilization 50%	0.4323	0.4764	0.4424	0.4476
66 2/3%	0.3382	0.3775	0.3486	0.3530
Cargo handling rate 5,000 tons/hr.				
Utilization 50%	0.3902	0.4157	0.3921	0.3957
66 2/3%	0.2961	0.3168	0.2983	0.3011
Required freight rate, 5,000 mile (one way) voyage, mils/ton - mile				
Cargo handling rate 1,250 tons/hr.				
50%	0.4859	0.5549	0.5072	0.5142
66 2/3%	0.3925	0.4566	0.4139	0.4203
Cargo handling rate 5,00o tons/hr.				
50%	0.4017	0.4336	0.4066	0.4103
66 2/3%	0.3083	0.3353	0.3133	0.3164

TABLE 5

Principal Characteristics
Concept Designs of Restricted Draft Bulk Carriers

Nominal DWT	60,000	125,000	200,000
Length, O.A., about	770'-0"	960'-0"	1015'-0"
Length, B.P.	740'-0"	920'-0"	970'-0"
Breadth, mld.	131'-0"	167'-6"	191'-9"
Depth, mld.	53'-6"	67'-3"	84'-0"
Draft, scantling	38'-6"	47'-6"	60'-0"
Draft, operating, mld.	35'-0"	45'-0"	55'-0"
Displacement, total, @ op'g. draft tons	77,225	158,000	243,500
Light ship weight, tons	15,585	31,030	41,360
Deadweight, total, tons	61,640	126,970	202,140
Cargo capacity, 100%, cu. ft.	2,788,600	5,648,250	9,034,900
Fuel capacity, 98%, tons	2,830	6,510	7,240
Ballast capacity, ex-peaks, 100%, tons	25,850	46,330	59,600
Shaft horsepower, max. continuous	15,000	30,000	32,500
Service speed (trial speed @ 80% max. continuous SHP and operating draft)	15 knots	16 knots	15 knots
Cruising range, about, miles	12,500	15,000	15,000
Complement	27	27	27

TABLE 6
Light Ship Weight Summaries

ITEM	MARAD WEIGHT GROUPS	CONCEPT DESIGN 60000DWT	125000DWT	200000DWT
1.0 Steel	0-9			
1.1 Cargo section		10350	22100	29100
1.2 Ends		1810	4100	6600
1.3 Forecastle		75	135	175
1.4 House		415	435	435
Total		12650	26770	36310
2.0 Outfit				
2.1 Passenger and crew	10-3,4;11-3,4,5;12-0,1,3, 5,6;13-7,8,9;14-0 through 9;15-1,3;16-0,1,2;17-0 through 5;18-3,4;19-2,4	329	373	399
2.2 Cargo				
2.2.1 Hatch covers	10-2	500	770	1010
2.2.2 Miscellaneous	10-0,1;11-1;12-4;13-0,1, 2,3; 15-2	21	29	36
2.3 Electric plant	19-3	80	85	90
2.4 Fixed				
2.4.1 Steering gear and rudder	19-1	130	150	170
2.4.2 Deck Machinery	15-0;19-0	250	340	410
2.4.3 Miscellaneous	11-0,2;12-2;15-4,8,9;17-6; 18-0,2,5,6,7;19-6	390	476	558
Total		1700	2223	2673
3.0 Machinery (Geared steam turbine)	20-0 through 29-4	780	1135	1170
Total, steel, outfit and machinery		15130	30128	40153
Margin		455	902	1207
Light ship weight		15585	31030	41360

TABLE 7

Light Ship
Weights and Centers Summary

Item	Weight-Tons	VCG Abv. B. L.	LCG Aft of F.P.
60,000 DWT/T=35'			
Steel	12,650	30.6	372.3
Outfit	1,700	47.9	424.3
Machinery	780	26.0	660.0
Margin	455	40.0	370.0
Light Ship	15,585	32.5	392.3
125,000 DWT/T=45'			
Steel	26,770	37.0	457.7
Outfit	2,223	63.0	523.0
Machinery	1,135	30.0	825.0
Margin	902	55.0	460.0
Light Ship	31,030	39.1	475.9
200,000 DWT/T=55'			
Steel	36,310	46.8	487.6
Outfit	2,673	72.6	538.2
Machinery	1,170	32.0	870.0
Margin	1,207	65.0	485.0
Light Ship	41,360	48.6	501.6

TABLE 8

Hull Form Characteristics

Nominal DWT	60,000	125,000	200,000
Length, B.P.	740'-0"	920'-0"	970'-0"
Breadth, mld.	131'-0"	167'-6"	191'-9"
Depth, mld.	53'-6"	67'-3"	84'-0"
L/D	13.83	13.68	11.55
B/D	2.45	2.49	2.28
Draft, operating, mld.	35'-0"	45'-0"	55'-0"
Displacement, mld, tons	76,950	157,500	242,700
C_B	0.794	0.795	0.830
C_P	0.796	0.798	0.835
L/B	5.65	5.49	5.06
B/T	3.74	3.72	3.49
L.C.B., FWD	2.5%	2.5%	2.5%
Tons/inch immersion	216.7	344.0	424.5
Approx. moment to trim one inch, ft-tons	12,010	23,843	32,150

TABLE 9

Structural Design Data

Nominal DWT	60,000	125,000	200,000
Design draft, ft	35'-0"	45'-0"	55'-0"
Scantling draft, ft	38'-6"	47'-6"	60'-0"
Design Requirements:			
Max. S.W.B.M., ft-tons	681,000	1,447,000	2,100,000
Max. shear amidships, tons	3,430	7,810	12,200
Section Modulus, required:			
Deck, $in.^2-ft^2$	165,000	343,200	463,200
Bottom, $in.^2-ft^2$	174,000	349,600	467,000
Shear stress amidships, allowable, $tons/in.^2$	4.75	4.75	4.75
Section Modulus, actual:			
Deck, $in.^2-ft^2$	165,300	354,000	466,000
Bottom, $in.^2-ft^2$	176,900	359,600	516,400
Shear stress amidships, actual, $tons/in.^2$	3.98	4.63	4.66

TABLE 10

Intact Stability Data
Maximum and Minimum Values of GM

Design	60,000 DWT T = 35'	125,000 DWT T = 45'	200,000 DWT T = 55'
Departure, homogeneous cargo, 10,000 mile voyage (one-way)			
KM, ft	62.2	80.2	88.8
KG, ft	30.3	38.3	47.6
GM, uncorrected, ft	31.9	41.9	41.2
Arrival, ore @ 12 cu.ft./ton, 5,000 mile voyage (one-way)			
KM, ft	62.4	80.5	89.2
KG, ft	25.7	33.4	41.5
GM, uncorrected, ft	36.7	47.1	47.7

TABLE 11

Summary of Capacities

60,000 DWT Dry Bulk Carrier

FUEL OIL TANKS				
Location Frames	Compartment	Tons, Fuel Oil, 98% Full	VCG Abv. B.L.	LCG Aft of F.D.
77-95	Fwd E.R. D.T. P	960	41	648
77-95	S	960	41	648
111-117	Aft E.R. D.T., Port Inboard	170	41	704
111-117	Port Outboard	285	43	702
111-117	Stbd Inboard	170	41	704
111-117	Stbd Outboard	285	43	702
	TOTAL	2,830 Tons		

Notes:

1. 1 Ton Fuel Oil = 37.23 cu. ft.

CARGO HOLDS				
Location Frames	Compartment	Vol., Cu. ft. 100%	VCG Abv. B.L.	LCG Aft of F.P.
25-32	1	290,745	30.4	65.5
32-38	2	329,115	29.2	150.1
38-44	3	332,325	27.2	214.0
44-50	4	332,325	27.2	278.0
50-56	5	332,325	27.2	342.0
56-62	6	332,325	27.2	406.0
62-67	7	322,355	29.6	469.5
67-72	8	282,245	31.2	533.1
72-77	9	234,860	34.9	597.3
	TOTAL	2,788,620		

Notes:

1. Hold Vol. includes 2'-0" in hatch coamings

TABLE 12

Summary of Capacities

60,000 DWT Dry Bulk Carrier

BALLAST TANKS				
Location Frames	Tank No.	Tons, S.W., 100%	VCG Abv. B.L.	LCG Aft of F.P.
25-32	Upper Wing No. 1-P&S	1190	48.2	90.5
32-38	2-P&S	1200	48.4	150.2
38-44	3-P&S	1220	48.2	214.0
44-50	4-P&S	1220	48.2	278.0
50-56	5-P&S	1220	48.2	342.0
56-62	6-P&S	1220	48.2	406.0
62-67	7-P&S	1220	48.2	470.0
67-72	8-P&S	1155	48.6	533.0
72-77	9-P&S	1135	48.8	596.8
25-32	Lower Wing No. 1-P&S	970	7.2	90.3
32-38	2-P&S	1300	7.1	154.0
38-44	3-P&S	1535	7.0	214.0
44-50	4-P&S	1535	7.0	278.0
50-56	5-P&S	1535	7.0	342.0
56-62	6-P&S	1440	7.5	404.8
62-67	7-P&S	1425	10.0	473.5
67-72	8-P&S	1995	15.9	535.7
72-77	9-P&S	1570	19.5	602.7
25-32	Double Bottom No. 1	375	3.2	89.4
32-38	2	445	2.8	150.0
38-44	3	425	2.8	214.0
44-50	4	425	2.8	278.0
50-56	5	425	2.8	342.0
56-62	6	445	2.6	406.0
62-67	7	415	2.8	468.5
67-72	8	470	3.4	533.6
72-77	9	1070	9.9	595.1

Notes:

1. 1 Ton Salt Water = 35 cu. ft.

TABLE 13

Summary of Loading Conditions

60,000 DWT Dry Bulk Carrier

Cond. No.	VOYAGE/CARGO	HOLDS No.	HOLDS % Full	FUEL Tons	CARGO DWT or SWB Tons	Δ, Total Tons	DRAFT, Mld. Dep.	DRAFT, Mld. Arr.	TRIM Dep.	TRIM Arr.	MAX. SWBM (*1) Ft.-Tons Dep.	MAX. SWBM (*1) Ft.-Tons Arr.
1	Homogeneous cargo, 5,000 miles	All	100	1,116	60,324	77,225	35'-0"	34'-7"	0" F	33" F	-109,000	-158,000
	46.5 cu.ft./Ton 10,000 miles	All	100	2,232	59,608	77,225	35'-0"	34'-4"	29" A	29" F	- 75,000	-134,000
	47.0 cu.ft./Ton											
2	Ore, 12 cu.ft./ton 5,000 miles	2	55%	1,116	60,324	77,225	35'-0"	34'-7"	0" F	33" F	560,000	512,000
		3	60%									
		7	53%									
		8	59%									
	10,000 miles			2,232	59,608	77,225	35'-0"	34'-4"	3" A	55" F	639,000	534,000
		2	59%									
		3	58%									
		7	50%									
		8	58%									
3	Ore, 18 cu.ft./ton 5,000 miles	1	62%	1,116	60,324	77,225	35'-0"	34'-7"	1" A	32" F	196,000	142,000
		3	81%									
		5	73%									
		7	70%									
		9	70%									
	10,000 miles	1	67%	2,232	59,608	77,225	35'-0"	34'-4"	2" A	56" F	321,000	204,000
		3	78%									
		5	75%									
		7	61%									
		9	72%									
4	Ballast 5,000 miles	-	-	1,116	25,348	42,249	20'-9"	20'-5"	118" A	40" A	273,000	200,000
	10,000 miles	-	-	2,232	22,828	40,845	20'-2"	19'-4"	110" A	15" F	414,000	250,000

(*1) Sign convention: + Hog, - Sag

TABLE 14

Summary of Capacities

125,000 DWT Dry Bulk Carrier

FUEL OIL TANKS				
Location Frames	Compartment	Tons, Fuel Oil, 98% Full	VCG Abv. B.L.	LCG Aft of F.D.
96-116	Fwd E.R. D.T. P	1800	52.0	800
96-116	S	1800	52.0	800
134-146	Aft E.R. D.T., Port Outboard	780	54.0	866
134-146	Port Inboard	675	52.0	869
134-146	Stbd Outboard	780	54.0	866
134-146	Stbd Inboard	675	52.0	869
	TOTAL	6510 Tons		

Notes:
1. 1 Ton Fuel Oil = 37.23 cu. ft.

CARGO HOLDS				
Location Frames	Compartment	Vol., Cu. ft. 100%	VCG Abv. B.L.	LCG Aft of F.P.
33-40	1	542,560	37.3	108.5
40-47	2	674,865	36.6	186.2
47-54	3	681,025	36.6	265.3
4-61	4	681,025	36.6	344.7
61-68	5	681,025	36.6	424.0
68-75	6	681,025	36.6	503.3
75-82	7	635,760	38.3	582.0
82-89	8	582,055	38.9	661.1
89-96	9	488,925	43.5	739.8
	TOTAL	5,648,265		

Notes:
1. Hold Vol. includes 2'-0" in hatch coamings

TABLE 15

Summary of Capacities

125,000 DWT Dry Bulk Carrier

BALLAST TANKS				
Location Frames		Tons, S.W., 100%	VCG Abv. B.L.	LCG Aft of F.P.
33-40	Upper Wing No. 1-P&S	1750	60.9	113.0
40-47	2-P&S	1750	61.0	187.2
47-54	3-P&S	1795	60.9	265.3
54-61	4-P&S	1795	60.9	344.6
61-68	5-P&S	1795	60.9	424.0
68-75	6-P&S	1795	60.9	503.3
75-82	7-P&S	1795	60.9	582.6
82-89	8-P&S	1795	60.9	662.0
89-96	9-P&S	1715	61.3	739.2
33-40	Lower Wing No. 1-P&S	1355	9.1	107.8
40-47	2-P&S	2015	6.8	191.2
47-54	3-P&S	2295	7.1	265.3
54-61	4-P&S	2295	7.1	344.6
61-68	5-P&S	2295	7.1	424.0
68-75	6-P&S	2295	7.1	501.8
75-82	7-P&S	2945	13.6	585.9
82-89	8-P&S	2545	19.0	662.9
89-96	9-P&S	2380	26.1	750.2
33-40	Double Bottom No. 1	990	4.0	111.0
40-47	2	905	3.3	186.0
47-54	3	910	3.3	265.3
54-61	4	910	3.3	344.6
61-68	5	910	3.3	424.0
68-75	6	910	3.3	503.3
75-82	7	860	4.1	581.1
82-89	8	1355	5.4	663.1
89-96	9	2165	9.6	738.9
23-33	Fwd. Deep Tanks -P&S	3430	41.2	58.0

Notes:

1. 1 Ton Salt Water = 35 cu. ft.

TABLE 16

Summary of Loading Conditions

125,000 DWT Dry Bulk Carrier

COND. No.	VOYAGE/CARGO	HOLDS No.	HOLDS % Full	FUEL Tons	CARGO DWT or SWB Tons	Δ, Total Tons	DRAFT, Mld. Dep.	DRAFT, Mld. Arr.	TRIM Dep.	TRIM Arr.	MAX. SWBM (*1) Ft.-Tons Dep.	MAX. SWBM (*1) Ft.-Tons Arr.
1	Homogeneous Cargo 5,000 miles 45.5 cu.ft./Ton	All	100	2,142	124,628	158,000	45'-0"	44'-5"	10" F	24" F	-465,410	-633,418
	10,000 miles 46.3 cu.ft./Ton	All	100	4,283	122,487	158,000	45'-0"	43'-9"	27" A	36" F	-330,000	-589,000
2	Ore, 12 cu.ft./Ton 5,000 miles	2 3 7 8	56% 58% 55% 64%	2,142	124,628	158,000	45'-0"	44'-5"	0	14" F	1,307,000	-1,192,000
	10,000 miles	2 3 7 8	56% 58% 61% 52%	4,283	122,487	158,000	45'-0"	43'-9"	3" F	67" F	1,447,000	1,227,000
3	Ore, 18 cu.ft./Ton 5,000 miles	1 3 5 7 9	72% 72% 74% 76% 73%	2,142	124,628	158,000	45'-0"	44'-5"	2" A	12" F	589,000	377,000
	10,000 miles	1 3 5 7 9	73% 74% 72% 75% 66%	4,283	122,487	158,000	45'-0"	43'-9"	0" F	64" F	783,000	385,000
4	Ballast 5,000 miles	3	100%	2,142	67,998	99,128	30'-9"	30"-2"	65" A	16" F	1,191,000	907,000
	10,000 miles	3	100%	4,283	67,998	101,370	31"-2"	30'-2"	104" A	16" F	1,415,000	907,000

(*1) Sign Convention: + Hog, - Sag

TABLE 17

Summary of Capacities

200,000 DWT Dry Bulk Carrier

CARGO HOLDS				
Location Frames	Compartment	Vol., Cu. Ft. 100%	VCG Abv. B.L.	LCG Aft of F.P.
34-41	1	807,815	54.5	108.1
41-48	2	1,080,270	45.1	195.0
48-55	3	1,080,270	45.1	279.0
55-62	4	1,080,270	45.1	373.0
62-69	5	1,080,270	45.1	447.0
69-76	6	1,078,655	45.1	531.0
76-83	7	1,061,935	45.5	614.7
83-90	8	997,080	47.5	694.4
90-97	9	769,335	55.2	784.3
	TOTAL	9,034,900		

FUEL OIL TANKS				
Location Frames	Compartment	Tons, Fuel Oil, 98% Full	VCG Abv. B.L.	LCG Aft of F.D.
97-105	Fwd E.R. D.T. P	1,430	64.0	837.0
97-105	S	1,430	64.0	837.0
124-132	AFT E.R. D.T. Port Outboard	930	66.0	916.0
124-132	Port Inboard	1,260	64.0	918.0
124-132	Stbd Outboard	930	66.0	916.0
124-132	Stbd Inboard	1,260	64.0	918.0
	TOTAL	7,240 Tons		

Notes:

1. 1 Ton Fuel Oil = 37.23 cu. ft.

TABLE 18

Summary of Capacities

200,000 DWT Dry Bulk Carrier

BALLAST TANKS				
Location Frames	Tank No.	Tons, S.W., 100%	VCG Abv. B.L.	LCG Aft of F.P.
34-41	Double Bottom No. 1	2840	10.7	114.0
41-48	2	1080	3.5	195.0
48-55	3	1080	3.5	279.0
55-62	4	1080	3.5	363.0
62-69	5	1080	3.5	447.0
69-76	6	1080	3.5	530.8
76-83	7	1335	3.2	613.8
83-90	8	1565	4.7	700.4
90-97	9	4385	14.6	780.6
34-41	Upper Wing No. 1-P&S	2530	77.0	116.9
41-48	2-P&S	2130	77.8	195.0
48-55	3-P&S	2025	77.8	279.0
55-62	4-P&S	2025	77.8	363.0
62-69	5-P&S	2025	77.8	447.0
69-76	6-P&S	2025	77.8	531.0
76-83	7-P&S	2025	77.8	615.0
83-90	8-P&S	2025	77.8	699.0
90-97	9-P&S	2025	77.8	783.0
34-41	Lower Wing No. 1-P&S	3525	10.7	127.0
41-48	2-P&S	2525	6.1	197.3
48-55	3-P&S	2525	6.1	279.0
55-62	4-P&S	2525	6.1	363.0
62-69	5-P&S	2525	6.1	447.0
69-76	6-P&S	2525	6.1	531.0
76-83	7-P&S	2790	8.3	618.4
83-90	8-P&S	2835	14.3	700.1
90-97	9-P&S	3465	21.9	778.3
25-34	Fwd. Deep Tanks -P&S	5900	49.5	47.0

Notes:

1. Hold volume includes 2'-0" depth of cargo in hatch coamings
2. Specific volumes assumed

   1 ton salt water — 35 cu. ft.

   1 ton fuel oil — 37.23 cu. ft.

TABLE 19

Summary of Loading Conditions

200,000 DWT Dry Bulk Carrier

COND. No.	VOYAGE/CARGO	HOLDS No.	HOLDS % Full	FUEL Tons	CARGO DWT or SWB Tons	Δ, Total Tons	DRAFT, Mld Dep.	DRAFT, Mld Arr.	TRIM Dep.	TRIM Arr.	MAX. SWBM (*1) Ft.-Tons Dep.	MAX. SWBM (*1) Ft.-Tons Arr.
1	Homogeneous Cargo 5,000 miles 45.5 cu.ft./Ton	All	100	2,411	199,529	243,500	55'-0"	54'-7"	4" F	34" F	-1,816,000	-2,040,000
	10,000 miles 46.1 cu.ft./Ton	All	100	4,822	197,118	243,500	55'-0"	54'-0"	8" A	49" F	-1,668,000	-2,072,000
2	Ore, 12 cu.ft./Ton 5,000 miles	1 3 5 7 9	41% 52% 52% 56% 43%	2,411	199,529	243,500	55'-0"	54'-7"	7" A	23" F	-1,522,000	-1,744,000
	10,000 miles	1 3 5 7 9	42% 53% 54% 51% 41%	4,822	197,118	243,500	55'-0"	54'-0"	5" F	62" F	-1,291,000	-1,704,000
3	Ore, 18 cu.ft./Ton 5,000 miles	1 3 5 7 9	62% 78% 78% 84% 65%	2,411	199,529	243,500	55'-0"	54'-7"	7" A	23" F	-1,522,000	-1,744,000
	10,000 miles	1 3 5 7 9	63% 79% 81% 77% 61%	4,822	197,118	243,500	55'-0"	54'-0"	5" F	62" F	-1,291,000	-1,704,000
4	Ballast 5,000 miles	4	100%	2,411	92,676	136,647	33'-0"	32'-7"	108" A	66" A	1,425,000	-1,195,000
	10,000 miles	4	100%	4,822	92,676	139,058	33'-7"	32'-7"	143" A	66" A	1,730,000	-1,195,000

(*1) Sign Convention: + Hog, - Sag

TABLE 20

Concept Design Capital Cost Estimate

NOMINAL DWT	60,000	125,000	200,000
Length, B.P.	740'-0"	920'-0"	970'-0"
Breadth, mld.	131'-0"	167'-6"	191'-9"
Depth, mld.	53'-6"	67'-3"	84'-0"
Draft, operating, mld.	35'-0"	45'-0"	55'-0"
Displacement, total	77,225	158,000	243,500
Light ship weight	15,585	31,030	41,360
Deadweight, total	61,640	126,970	202,140
Base cost, one ship			
Steel	$7,327,000	$14,010,000	$18,630,000
Outfit	6,268,000	7,730,000	8,737,000
Machinery	3,705,000	5,250,000	5,508,000
Total, one ship	$17,300,000	$26,990,000	$32,875,000
Adjusted cost, one ship	$12,044,000	$18,790,000	$22,888,000
Each of three	10,599,000	16,535,000	20,141,000
Each of five	10,117,000	15,784,000	19,226,000
Each of ten	9,635,000	15,032,000	18,310,000
Cost ratios, each of five basis			
$/DWT	$164.13	$124.31	$ 95.11
$/Light ship	$649.15	$508.67	$464.85

TABLE 21

Comparison of Characteristics Computer vs.
Concept Designs Restricted Draft Bulk Carriers

Nominal DWT	60,000		125,000		200,000	
Design Method	Computer	Concept Des.	Computer	Concept Des.	Computer	Concept Des.
Draft, mld.	35'-0"	35'-0"	45'-0"	45'-0"	55'-0"	55'-0"
Length, B.P.	740'-0"	740'-0"	920'-0"	920'-0"	970'-0"	970'-0"
Breadth, mld.	131'-0"	131'-0"	167'-6"	167'-6"	191'-9"	191'-9"
Depth, mld.	52'-0"	53'-6"	65'-3"	67'-3"	81'-0"	84'-0"
C_B	0.790	0.794	0.795	0.795	0.827	0.830
Deadweight, tons	60,000	61,640	125,000	126,970	200,000	202,140
Service speed, knots	15	15	16	16	15	15
SHP, max.	15,000	15,000	28,500	30,000	32,500	32,500
Weight						
Steel	13,450	12,650	27,300	26,770	35,275	36,310
Outfit	1,950	1,700	3,100	2,223	4,050	2,673
Machinery	750	780	1,100	1,135	1,175	1,170
Total	16,150	15,130	31,500	30,128	40,500	40,153
Margin	500	455	950	902	1,200	1,207
Light ship weight	16,650	15,585	32,450	31,030	41,700	41,360
Capital cost, each of five ships	$10,629,000	$10,117,000	$16,935,000	$15,784,000	$20,757,000	$19,226,000
Cost ratios						
$/DWT, Actual	$177.15	$164.13	$135.48	$124.31	$103.79	$ 95.11
$/(Light ship ex margin)	$658.14	$668.67	$537.62	$523.90	$512.52	$478.79

TABLE 22

Comparison of Characteristics and Costs

60,000 DWT Restricted Draft and Conventional Designs

OPERATING DRAFT, Mld.	35 Ft.	35 Ft.	40 Ft.
Design method	Computer	Concept Design	Computer
Length, B.P.	740'-0"	740'-0"	700'-0"
Breadth, mld.	131'-0"	131'-0"	116'-0"
Depth, mld.	52'-0"	53'-6"	56'-1"
C_B	0.790	0.794	0.796
Displacement, total	76,650	77,225	73,875
Light ship weight	16,650	15,585	13,900
Deadweight, total	60,000	61,640	59,975
C_{DW}	0.783	0.798	0.812
Shaft horsepower, max.	14,600	15,000	14,800
Service speed (*1)	15	15	15
L/B	5.65	5.65	6.03
L/D	14.23	13.83	12.49
B/T	3.74	3.74	2.90
Capital cost, each of 5	$10,629,000	$10,117,000	$9,745,000
$/DWT	$177.15	$164.13	$162.48
RFR, 5,000 mile voyage, one-way mils/ton-mile			
Cargo rate 1,250 tons/hr.			
Utilization 50%	0.6998	0.6693	0.6671
66⅔%	0.5422	0.5189	0.5166
Cargo rate 5,000 tons/hr.			
Utilization 50%	0.6477	0.6188	0.6182
66⅔%	0.4901	0.4682	0.4677
RFR, 10,000 mile voyage, one-way mils/ton-mile			
Cargo rate 1,250 tons/hr.			
Utilization 50%	0.6727	0.6423	0.6421
66⅔%	0.5132	0.4906	0.4897
Cargo rate 5,000 tons/hr.			
Utilization 50%	0.6467	0.6172	0.6177
66⅔%	0.4872	0.4654	0.4653

(*1) Trial speed @ 80% max. SHP and operating draft.

TABLE 23

Comparison of Characteristics

125,000 DWT Restricted Draft and Conventional Designs

OPERATING DRAFT, Mld.	45 Ft.	45 Ft.	53 Ft.
Design Method	Computer	Cóncept Design	Computer
Length, B.P.	920'-0"	920'-0"	875'-0"
Breadth, mld.	167'-6"	167'-6"	141'-7"
Depth, mld.	65'-3"	67'-3"	75'-0"
C_B	0.795	0.795	0.807
Displacement, total	157,500	158,000	151,500
Light ship weight	32,500	31,030	26,500
Deadweight, total	125,000	126,970	125,000
C_{DW}	0.794	0.804	0.825
Shaft horsepower, max.	28,500	30,000	27,850
Service speed	16	16	16
L/B	5.49	5.49	6.18
L/D	14.10	13.68	11.66
B/T	3.72	3.72	2.67
Capital cost, each of 5	$16,935,000	$15,784,000	$15,045,000
$/DWT	$135.48	$124.31	$120.36
RFR, 5,000 mile voyage, 1-way mils/ton-mile			
Cargo rate 1,250 tons/hr.			
Utilization 50%	0.5708	0.5492	0.5276
66⅔%	0.4548	0.4376	0.4200
Cargo rate 5,000 tons/hr.			
Utilization 50%	0.4907	0.4731	0.4546
66⅔%	0.3747	0.3566	0.3470
RFR, 10,000 mile voyage, 1-way mils/ton-mile			
Cargo rate 1,250 tons/hr.			
Utilization 50%	0.5220	0.5037	0.4830
66⅔%	0.4048	0.3901	0.3744
Cargo rate 5,000 tons/hr.			
Utilization 50%	0.4819	0.4656	0.4465
66⅔%	0.3648	0.3519	0.3379

TABLE 24

Comparison of Characteristics

200,000 DWT Restricted Draft and Conventional Designs

OPERATING DRAFT, Mld.	55 Ft.	55 Ft.	63 Ft.
Design Method	Computer	Concept Design	Computer
Length B.P.	970'-0"	970'-0"	970'-0"
Breadth, mld.	191'-9"	191'-9"	164'-6"
Depth, mld.	81'-0"	84'-0"	90'-6"
C_B	0.827	0.830	0.827
Displacement, total	241,700	243,500	237,575
Light ship weight	41,700	41,360	37,575
Deadweight, total	200,000	202,140	200,000
C_{DW}	0.827	0.830	0.841
Shaft horsepower, max.	32,500	32,500	33,200
Service speed	15	15	15
L/B	5.06	5.06	5.90
L/D	11.98	11.55	10.72
B/T	3.49	3.49	2.61
Capital cost, each of 5	$20,757,000	$19,225,000	$19,430,000
$/DWT	$103.79	$95.11	$97.15
RFR, 5,000 mile voyage, 1-way mils/ton-mile			
Cargo rate 1,250 tons/hr.			
Utilization 50%	0.5072	0.4803	0.4878
66⅔%	0.4139	0.3919	0.3977
Cargo rate 5,000 tons/hr.			
Utilization 50%	0.4066	0.3851	0.3923
66⅔%	0.3133	0.2968	0.3022
RFR, 10,000 mile voyage, 1-way mils/ton-mile			
Cargo rate 1,250 tons/hr.			
Utilization 50%	0.4424	0.4190	0.4265
66⅔%	0.3486	0.3303	0.3358
Cargo rate 5,000 tons/hr.			
Utilization 50%	0.3921	0.3714	0.3787
66⅔%	0.2983	0.2827	0.2880

TABLE 25

Annual Operating Costs
60,000 DWT Restricted Draft & Conventional Designs

Operating Draft, Mld.	35 ft	35 ft	40 ft
Design Method	Computer	Concept Design	Computer
Operation & Support, $/Yr.			
Manning	$ 202,500	$ 202,500	$ 202,500
Subsistence	22,630	22,630	22,630
Stores & Supplies	33,180	33,650	33,240
Maintenance & Repair	105,380	106,600	101,320
H & M Insurance	115,650	110,870	106,010
P & I Insurance	20,400	20,760	19,210
Total	$ 499,740	$ 497,010	$ 484,910
Fuel Cost, $/Yr.			
5,000 MI. Voyage			
Cargo rate 1,250 tons/hr.			
Utilization 50%	$ 536,170	$ 548,930	$ 542,810
66 2/3%	519,910	531,820	526,380
Cargo rate 5,000 tons/hr.			
Utilization 50%	577,970	593,200	585,280
66 2/3%	572,910	587,840	580,150
10,000 MI. Voyage			
Cargo rate 1,250 tons/hr.			
Utilization 50%	$ 567,230	$ 581,180	$ 574,340
66 2/3%	556,990	571,260	564,940
Cargo rate 5,000 tons/hr.			
Utilization 50%	589,650	605,150	597,150
66 2/3%	587,410	602,360	594,880

TABLE 26

Annual Operating Costs

125,000 DWT Restricted Draft & Conventional Designs

Operating Draft, Mld.	45 ft	45 ft	53 ft
Design Method	Computer	Concept Design	Computer
Operation & Support, $/Yr.			
Manning	$ 202,500	$ 202,500	$ 202,500
Subsistence	22,630	22,630	22,630
Stores & Supplies	51,050	51,940	50,830
Maintenance & Repair	147,270	149,850	141,060
H & M Insurance	237,090	222,470	210,630
P & I Insurance	32,630	33,390	30,820
Total	$ 693,170	$ 682,780	$ 658,470
Fuel Cost, $/Yr.			
5,000 MI. Voyage			
Cargo rate 1,250 tons/hr.			
Utilization 50%	$ 930,760	$ 974,980	$ 910,720
66 2/3%	885,100	917,710	858,550
Cargo rate 5,000 tons/hr.			
Utilization 50%	1,089,180	1,144,580	1,064,530
66 2/3%	1,068,630	1,135,620	1,044,240
10,000 MI. Voyage			
Cargo rate 1,250 tons/hr.			
Utilization 50%	$1,041,920	$1,088,300	$1,013,620
66 2/3%	1,000,720	1,050,080	978,890
Cargo rate 5,000 tons/hr.			
Utilization 50%	1,130,530	1,188,440	1,104,410
66 2/3%	1,118,640	1,176,200	1,093,290

TABLE 27

Annual Operating Costs

200,000 DWT Restricted Draft & Conventional Designs

Operating Draft, Mld.		55 ft	55 ft	63 ft
Design Method		Computer	Concept Design	Computer
Operating & Support, $/Yr.				
Manning		$ 202,500	$ 202,500	$ 202,500
Subsistence		22,630	22,630	22,630
Stores & Supplies		67,740	68,180	67,970
Maintenance & Repair		189,140	193,800	183,910
H & M Insurance		365,320	340,340	341,970
P & I Insurance		44,860	46,220	43,340
Total		$ 892,190	$ 873,670	$ 862,320
Fuel Cost, $/Yr.				
5,000 MI. Voyage				
Cargo rate 1,250 tons/hr.				
Utilization	50%	$ 992,480	$ 990,730	011,820
	66 2/3%	924,990	923,500	948,610
Cargo rate 5,000 tons/hr.				
Utilization	50%	1,213,880	1,212,140	1,239,300
	66 2/3%	1,182,520	1,181,140	1,218,240
10,000 MI. Voyage				
Cargo rate 1,250 tons/hr.				
Utilization	50%	$1,132,500	$1,131,710	$1,155,830
	66 2/3%	1,081,720	1,081,660	1,103,530
Cargo rate 5,000 tons/hr.				
Utilization	50%	1,273,010	1,271,850	1,300,060
	66 2/3%	1,254,110	1,253,190	1,280,610

TABLE 28

Annual Productivity

60,000 DWT Restricted Draft & Conventional Designs

Operating Draft, Mld.	35 ft	35 ft	40 ft
Design, Method	Computer Design	Concept Design	Computer Design
Length, B. P.	740'-0"	749'-0"	700'-0"
Deadweight, total, tons	60,000	61,640	59,975
Productivity, (ton-miles/yr) x 10^{-6}			
5,000 mile voyage, one-way			
Cargo rate 1,250 tons/hr.			
Utilization 50%	3,154	3,228	3,152
66 2/3%	4,040	4,131	4,037
Cargo rate 5,000 tons/hr.			
Utilization 50%	3,471	3,563	3,469
66 2/3%	4,576	4,698	4,573
10,000 mile voyage, one-way			
Cargo rate 1,250 tons/hr.			
Utilization 50%	3,328	3,414	3,325
66 2/3%	4,338	4,449	4,342
Cargo rate 5,000 tons/hr.			
Utilization 50%	3,496	3,592	3,493
66 2/3%	4,638	4,757	4,634

TABLE 29

Annual Productivity

125,000 DWT Restricted Draft & Conventional Designs

Operating Draft, Mld.	45 ft	45 ft	53 ft
Design Method	Computer Design	Concept Design	Computer Design
Length, B. P.	920'-0"	920'-0"	875'-0"
Deadweight, total	125,000	126,970	125,000
Productivity, (ton-miles/yr) x 10^{-6}			
5,000 mile voyage, one-way			
Cargo rate 1,250 tons/hr.			
Utilization 50%	6,111	6,185	6,113
66 2/3%	7,640	7,631	7,552
Cargo rate 5,000 tons/hr.			
Utilization 50%	7,432	7,538	7,434
66 2/3%	9,678	9,975	9,682
10,000 mile voyage, one-way			
Cargo rate 1,250 tons/hr.			
Utilization 50%	6,929	6,970	6,886
66 2/3%	9,238	8,899	9,181
Cargo rate 5,000 tons/hr.			
Utilization 50%	7,655	7,754	7,660
66 2/3%	10,077	10,224	10,084

TABLE 30

Annual Productivity

200,000 DWT Restricted Draft & Conventional Designs

Operating Draft, Mld.	55 ft	55 ft	63 ft
Design Method	Computer Design	Concept Design	Computer Design
Length, B. P.	970'-0"	970'-0"	970'-0"
Deadweight, total	200,000	202,140	200,000
Productivity, (ton-miles/yr.) x 10^{-6}			
5,000 mile voyage, one-way			
Cargo rate 1,250 tons/hr.			
Utilization 50%	8,232	8,292	8,230
66 2/3%	9,923	9,990	10,012
Cargo rate 5,000 tons/hr.			
Utilization 50%	10,818	10,916	10,816
66 2/3%	13,936	14,061	14,104
10,000 mile voyage, one-way			
Cargo rate 1,250 tons/hr.			
Utilization 50%	9,755	9,842	9,750
66 2/3%	12,226	12,334	12,219
Cargo rate 5,000 tons/hr.			
Utilization 50%	11,374	11,479	11,154
66 2/3%	14,879	15,016	14,871

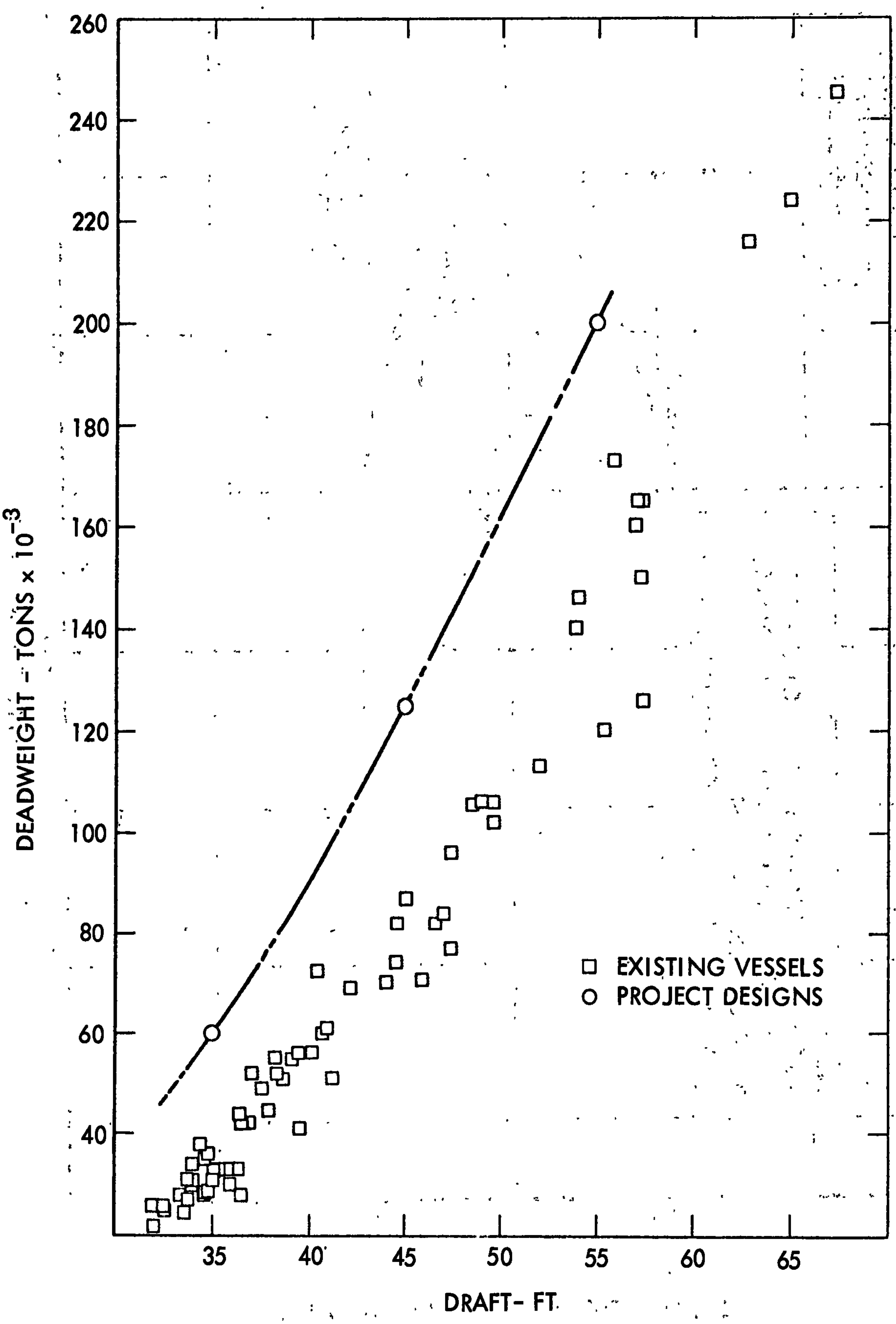


FIGURE 1 - DEADWEIGHT VS. DRAFT FOR DRY BULK, OBO AND ORE-OIL CARRIERS

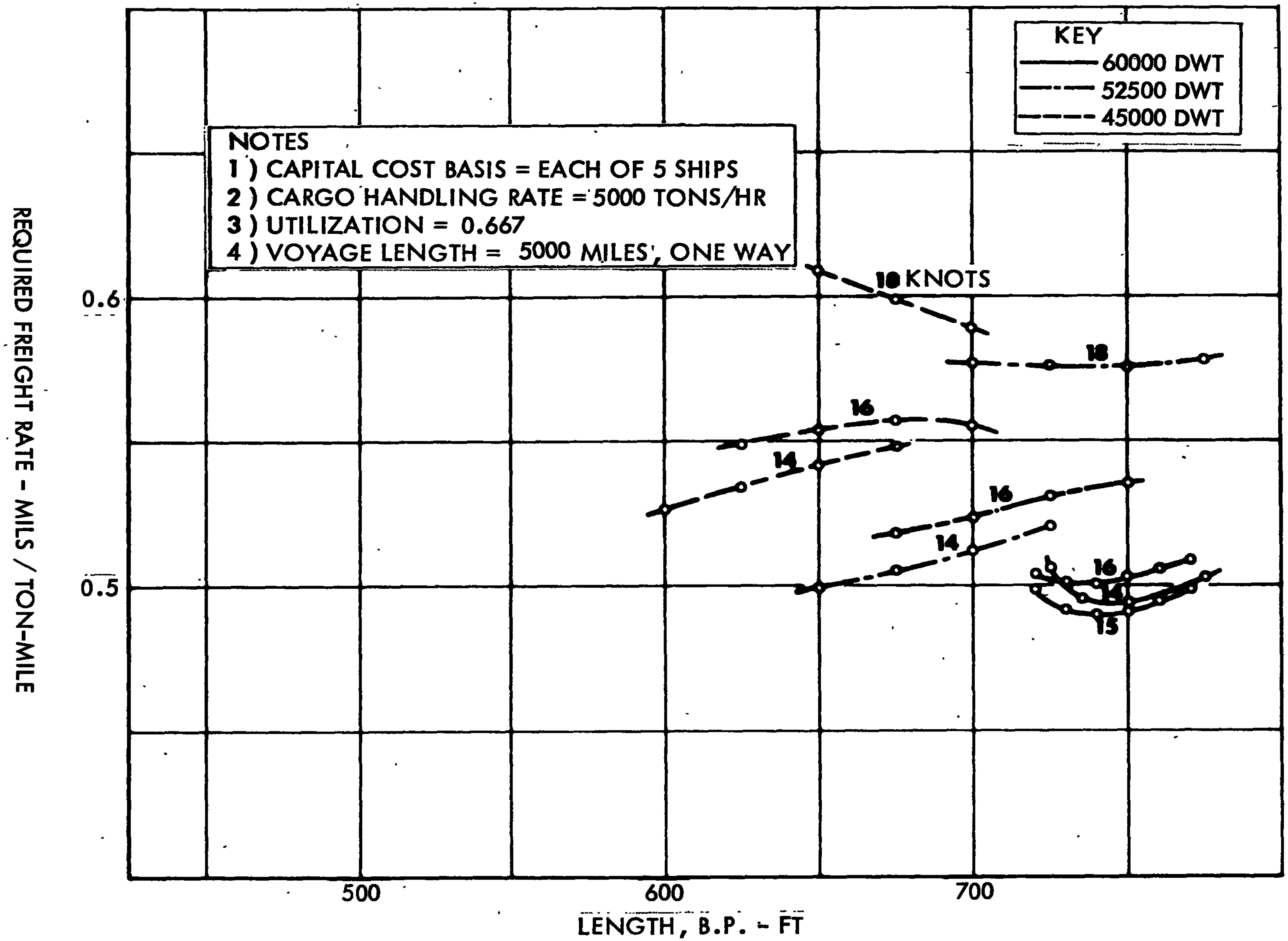


FIGURE 2 - REQUIRED FREIGHT RATE VS. LENGTH B. P. FOR 35 FOOT DRAFT

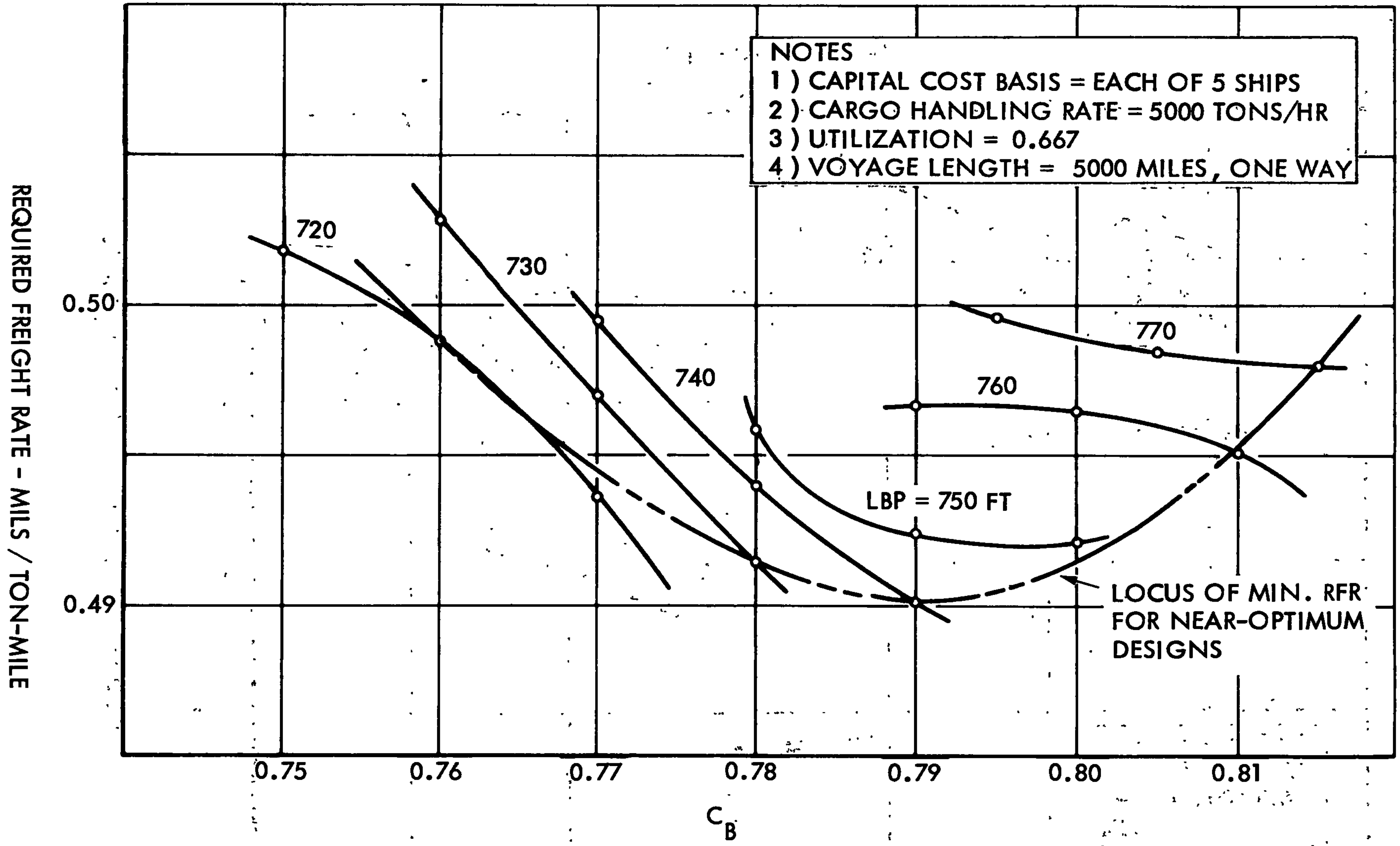


FIGURE 3 - REQUIRED FREIGHT RATE VS. LENGTH AND BLOCK COEFFICIENT FOR 60,000 DWT, SERVICE SPEED 15 KNOTS

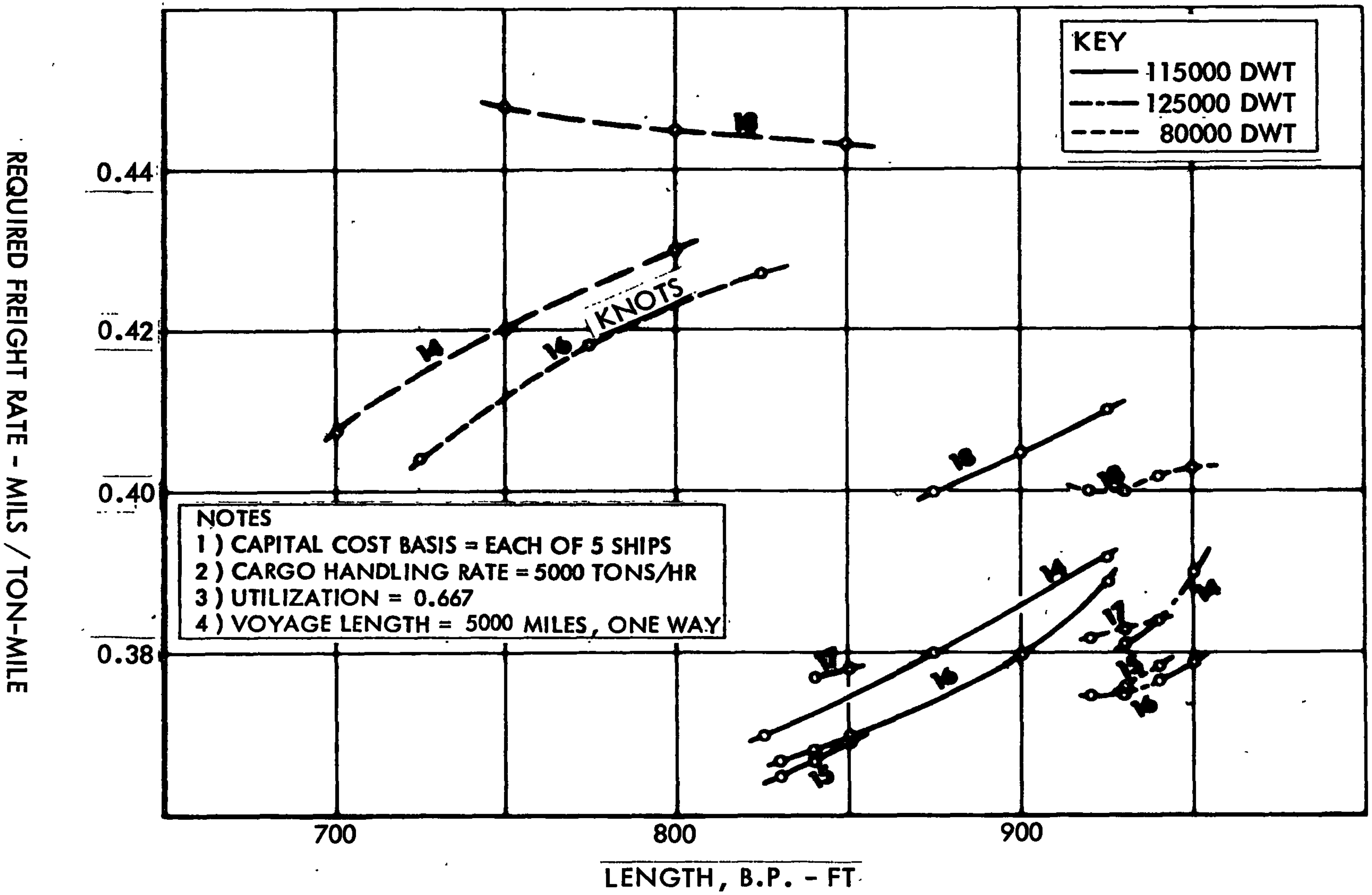


FIGURE 4 - REQUIRED FREIGHT RATE VS. LENGTH FOR 45 FOOT DRAFT

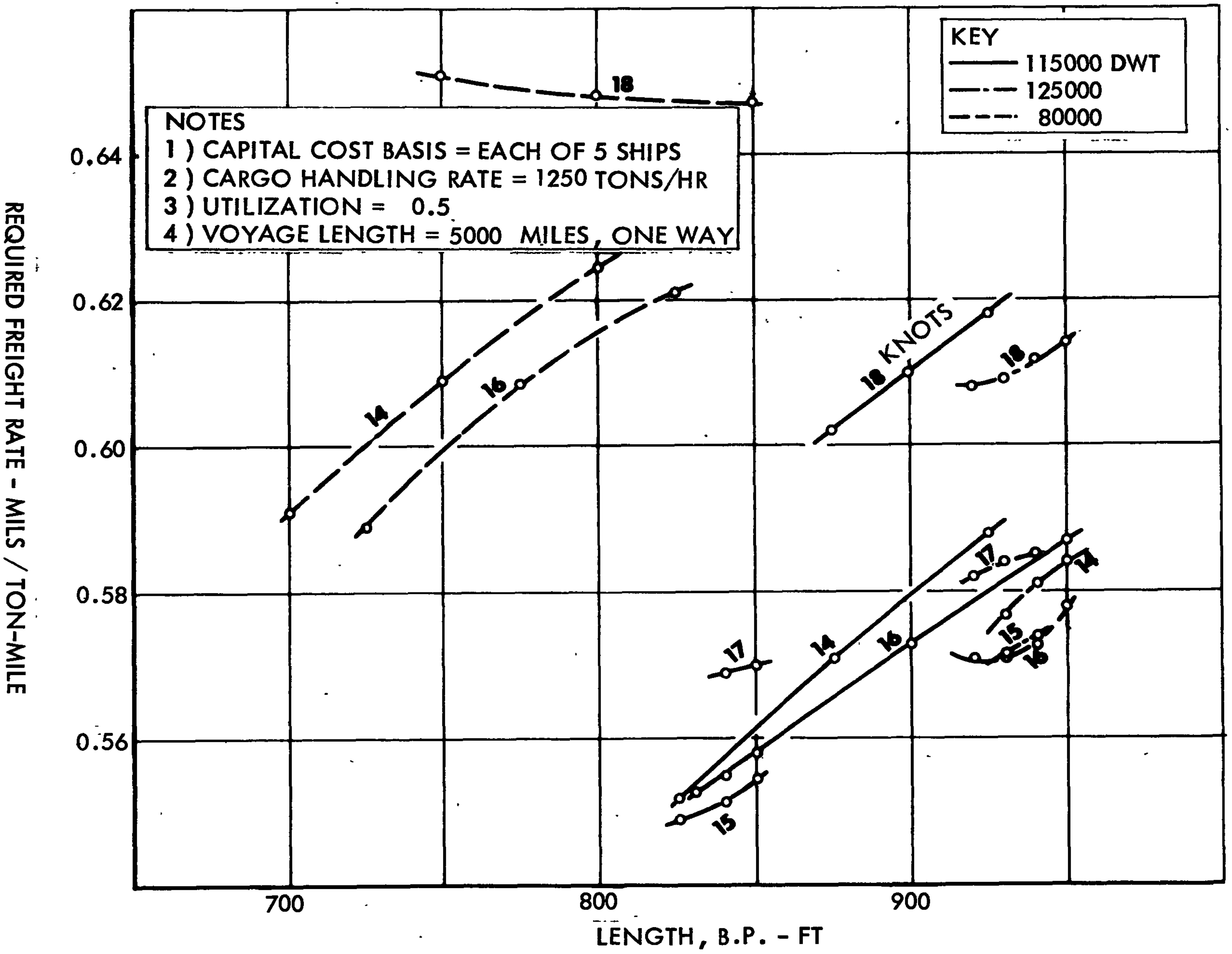


FIGURE 5 - REQUIRED FREIGHT RATE VS. LENGTH FOR 45 FOOT DRAFT

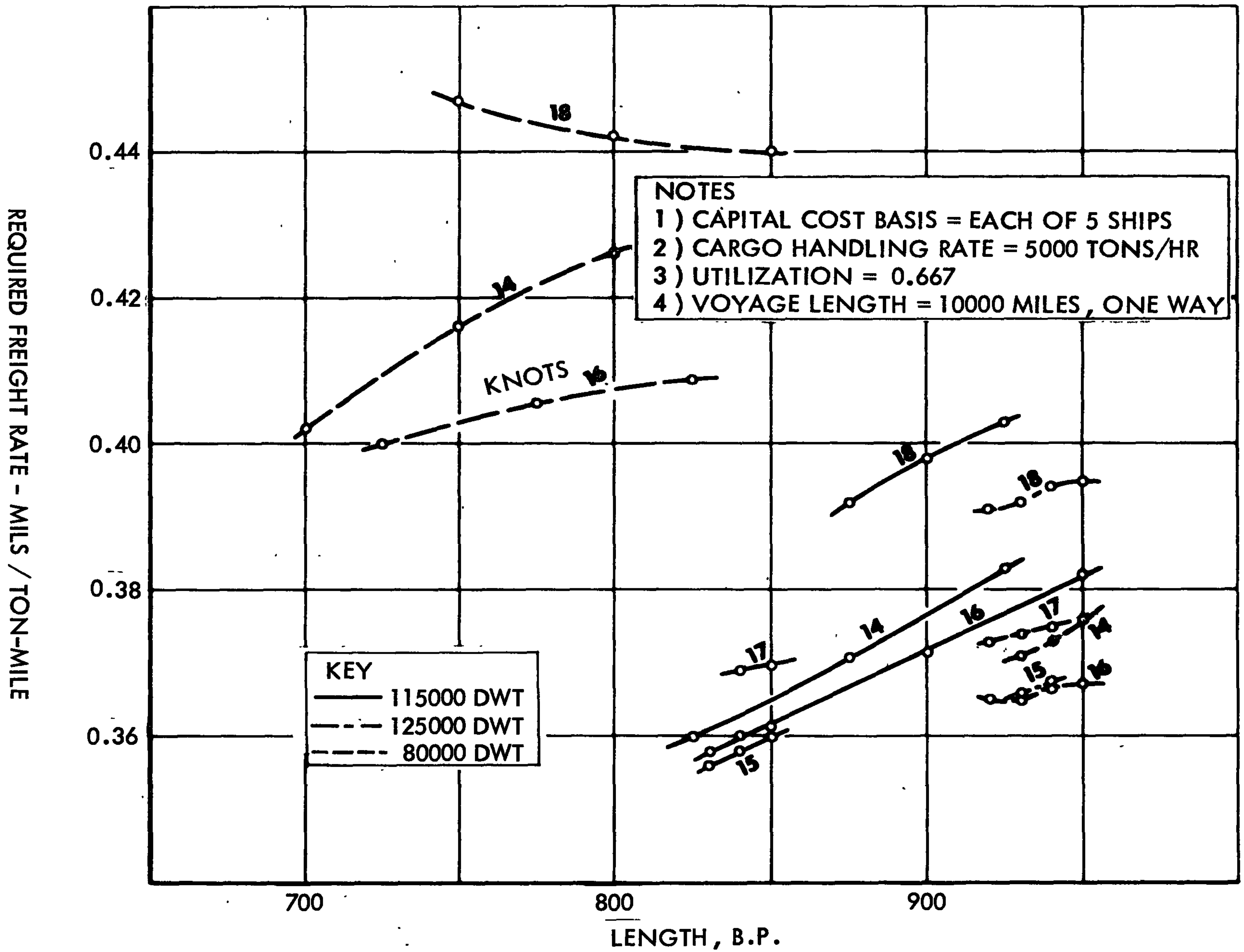


FIGURE 6 - REQUIRED FREIGHT RATE VS. LENGTH FOR 45 FOOT DRAFT

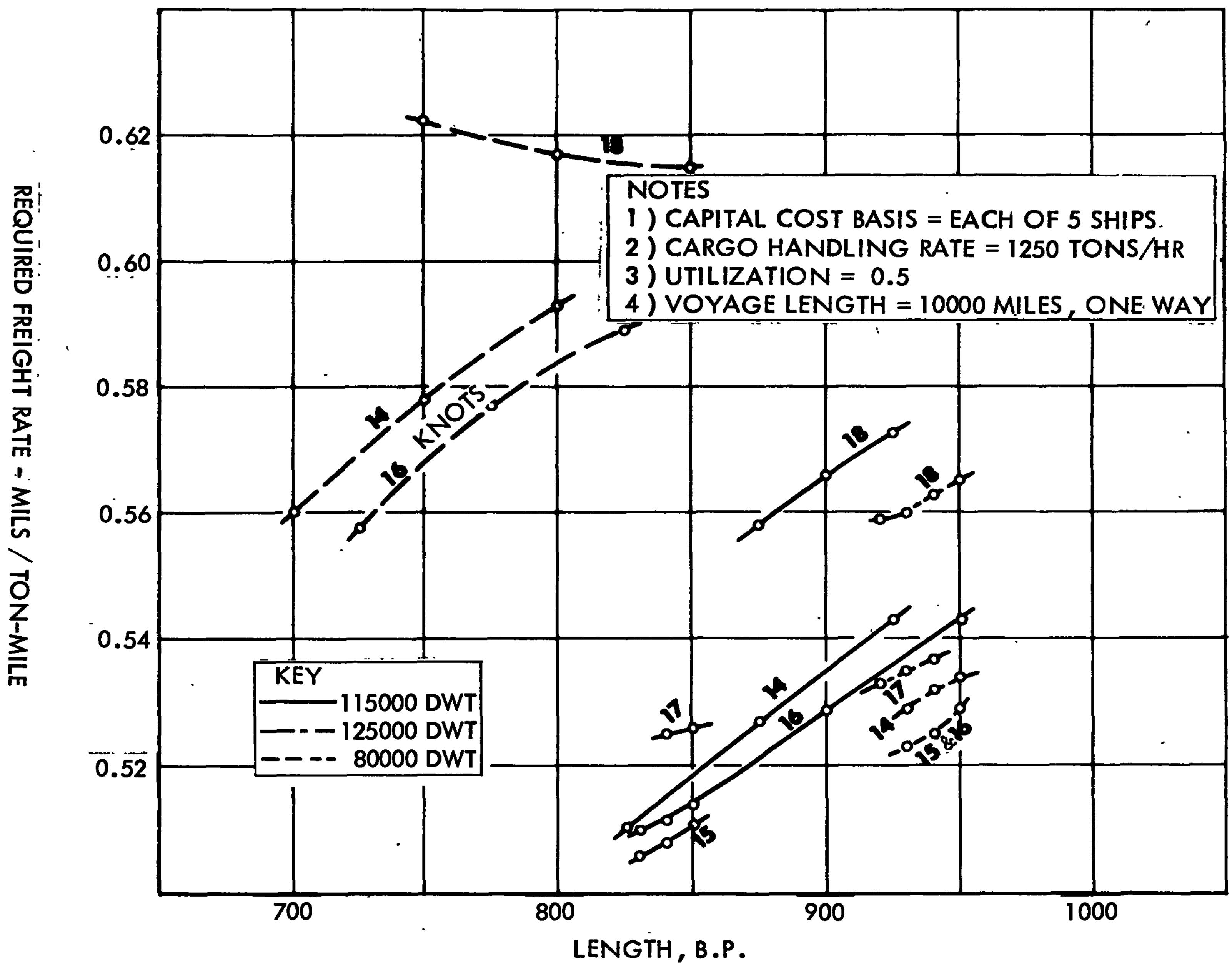


FIGURE 7 - REQUIRED FREIGHT RATE VS. LENGTH FOR 45 FOOT DRAFT

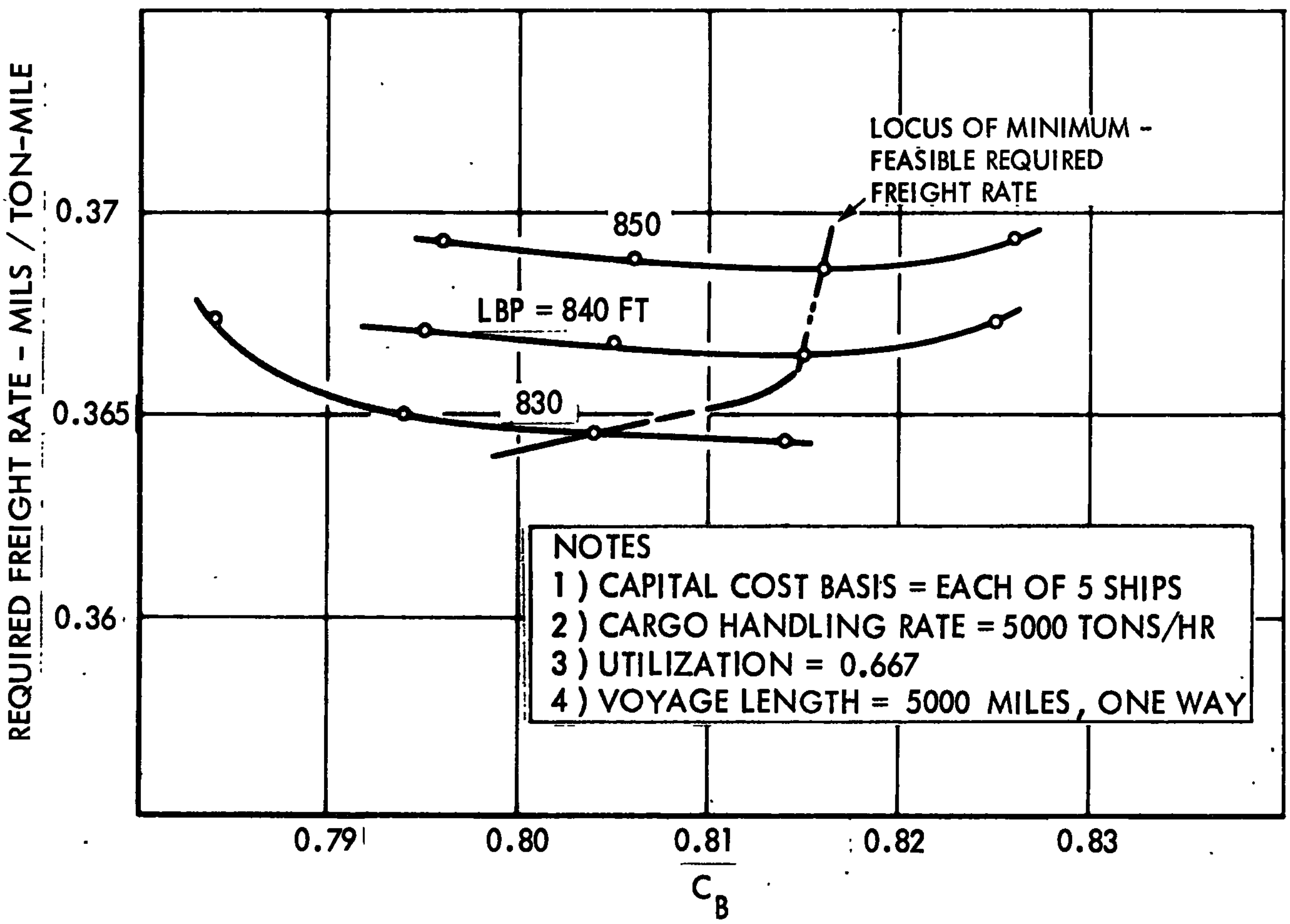


FIGURE 8 - REQUIRED FREIGHT RATE VS. BLOCK COEFFICIENT FOR 115,000 DWT, SERVICE SPEED 15 KNOTS

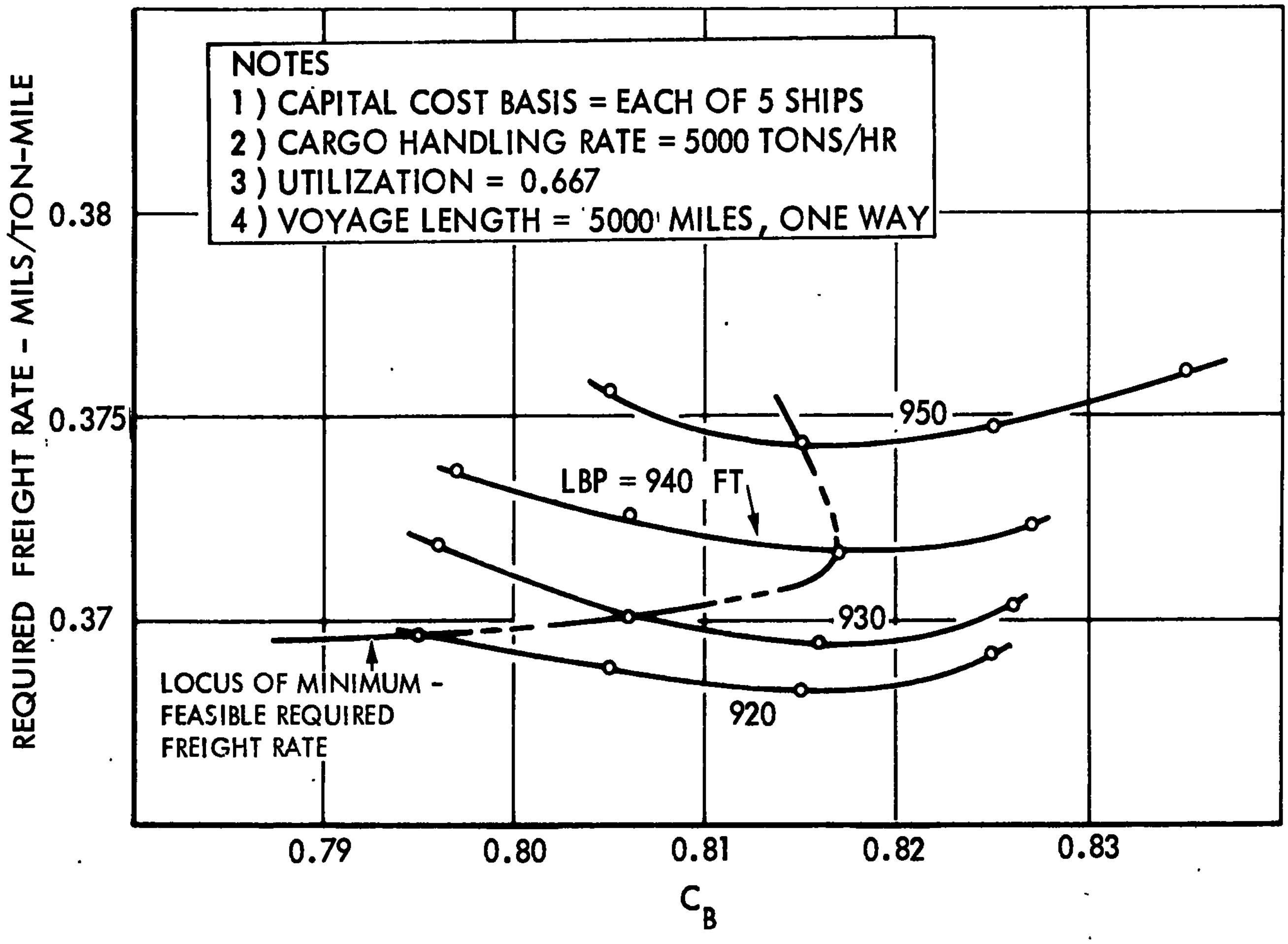


FIGURE 9 - REQUIRED FREIGHT RATE VS. BLOCK COEFFICIENT FOR 125,000 DWT, SERVICE SPEED 16 KNOTS

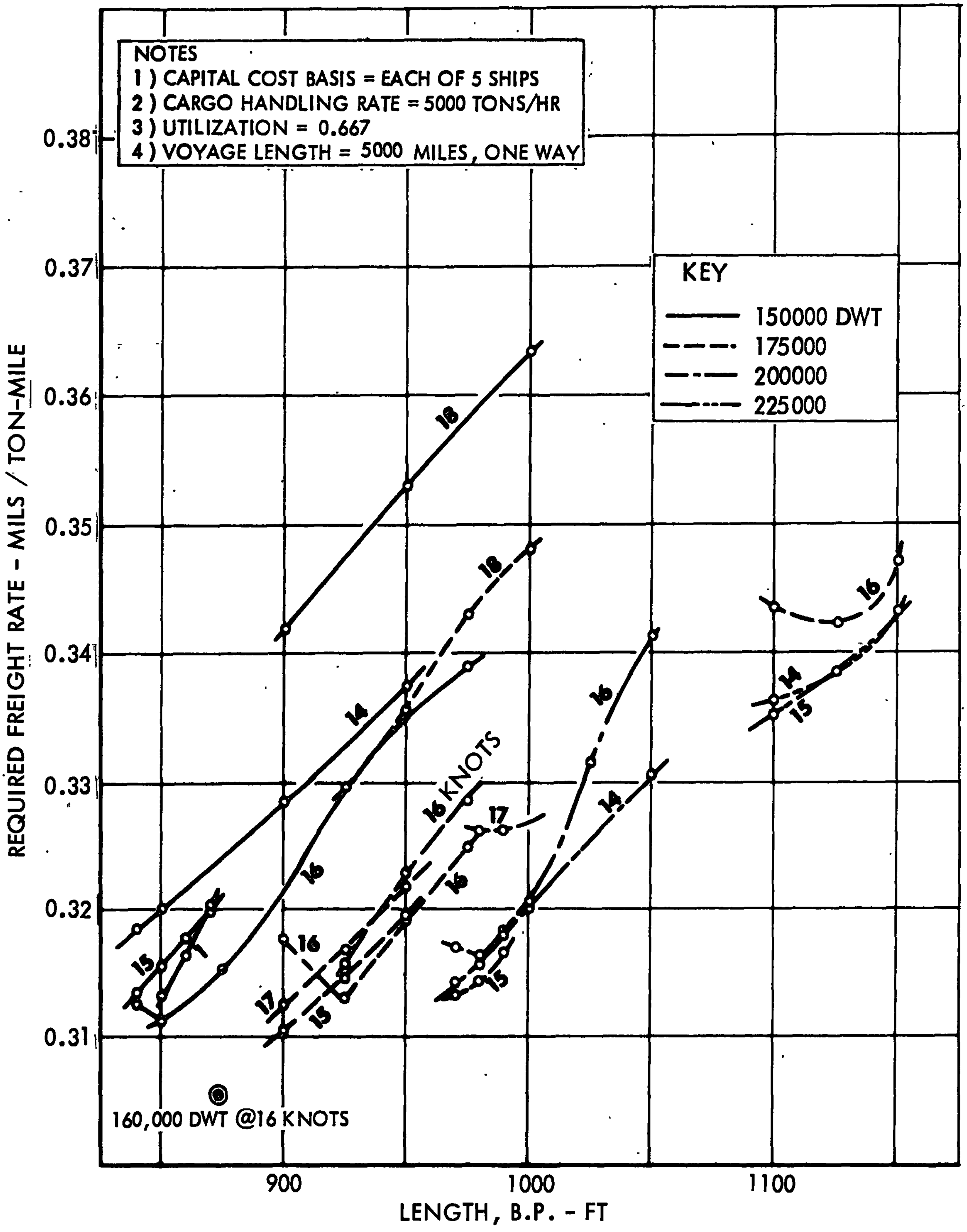


FIGURE 10 - REQUIRED FREIGHT RATE VS. LENGTH FOR 55 FOOT DRAFT

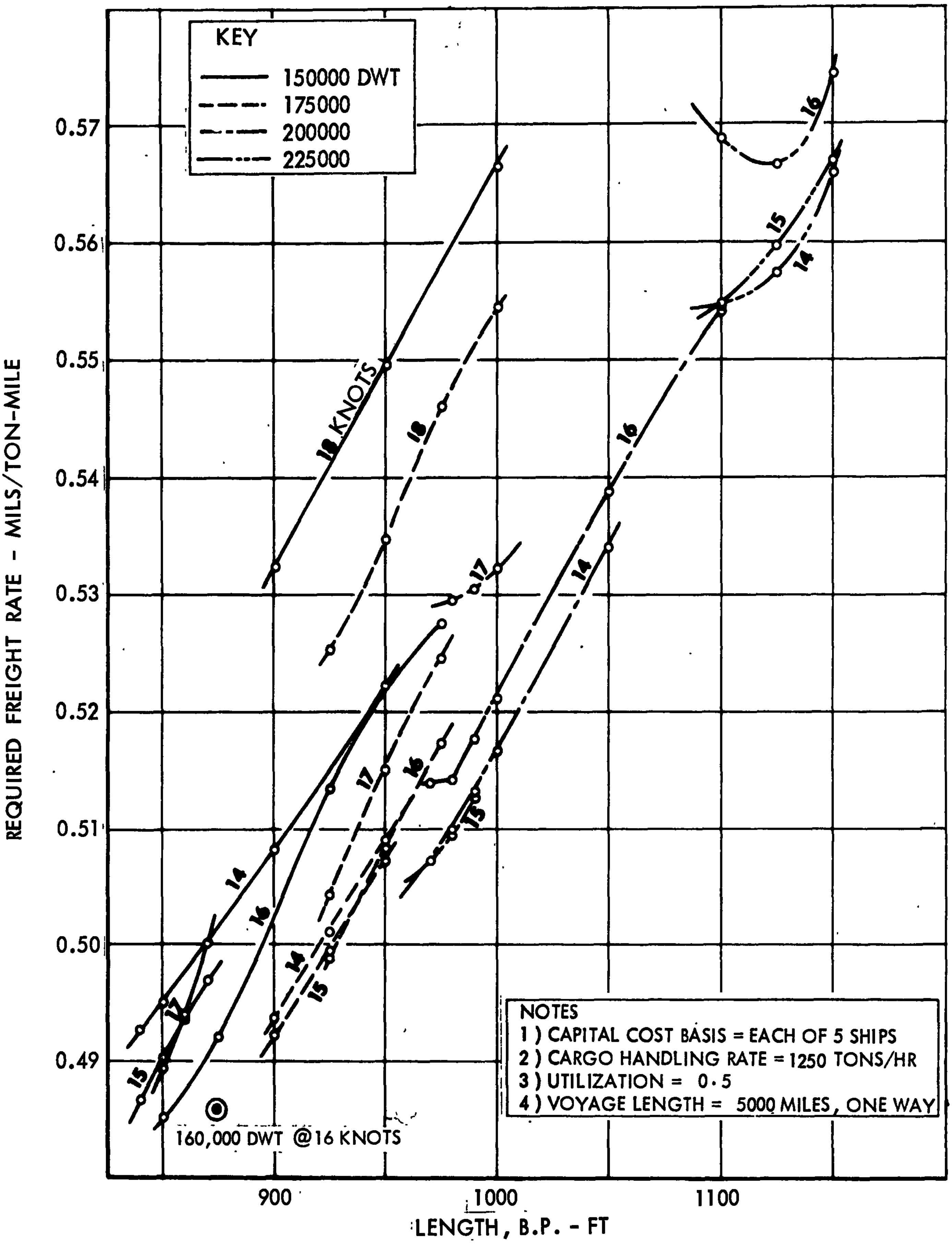


FIGURE 11 - REQUIRED FREIGHT RATE VS. LENGTH FOR 55 FOOT DRAFT

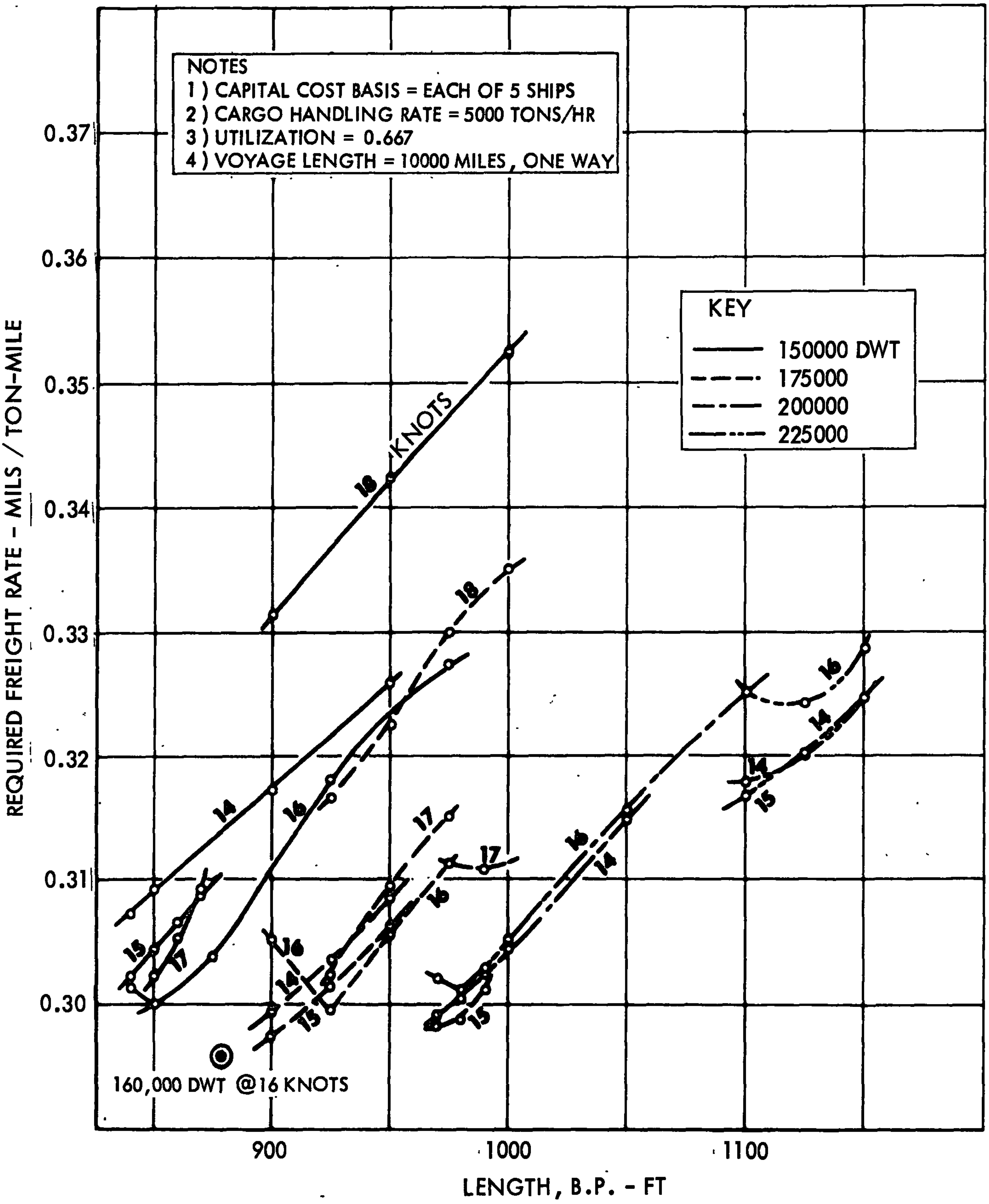


FIGURE 12 - REQUIRED FREIGHT RATE VS. LENGTH FOR 55 FOOT DRAFT

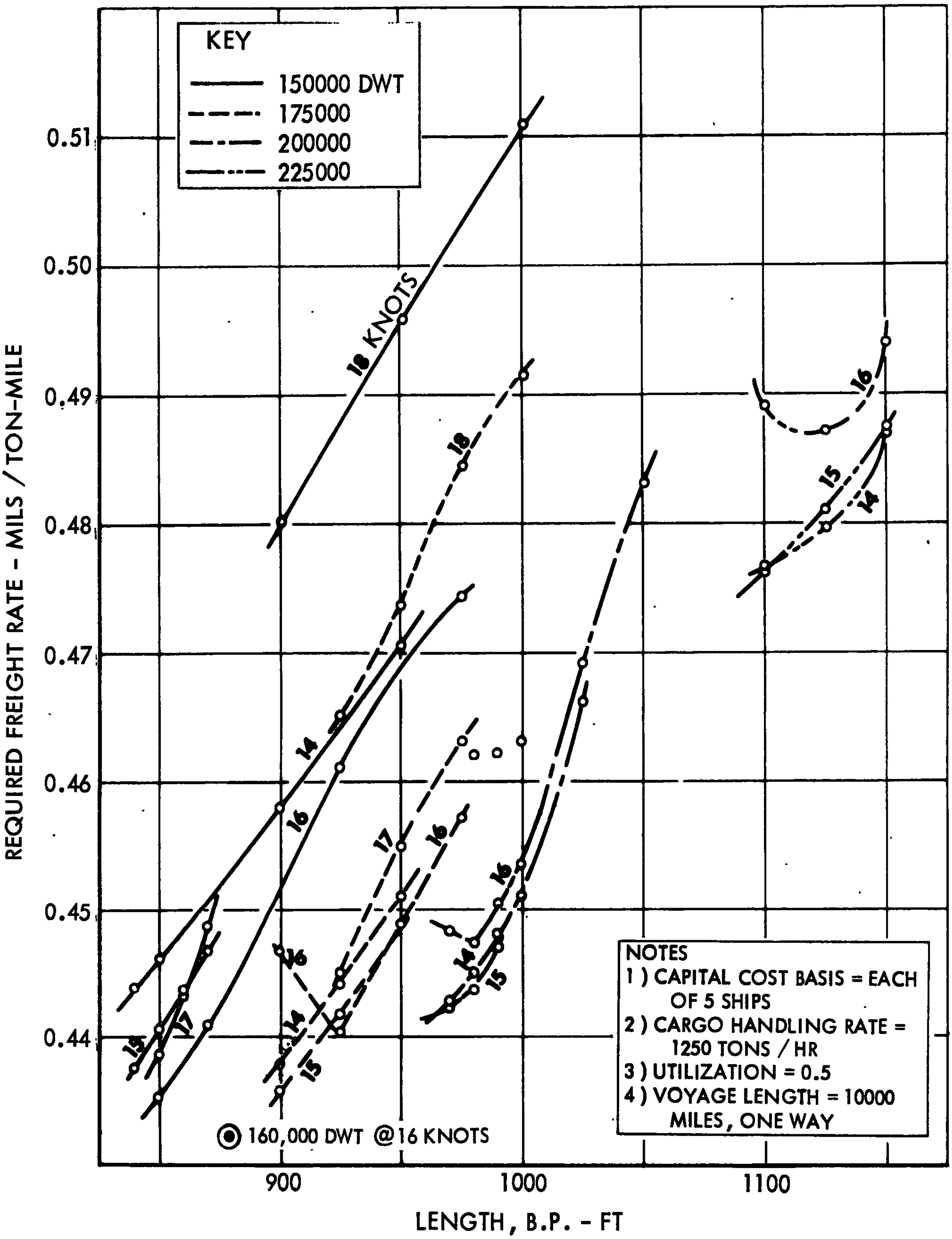


FIGURE 13 - REQUIRED FREIGHT RATE VS. LENGTH FOR 55 FOOT DRAFT

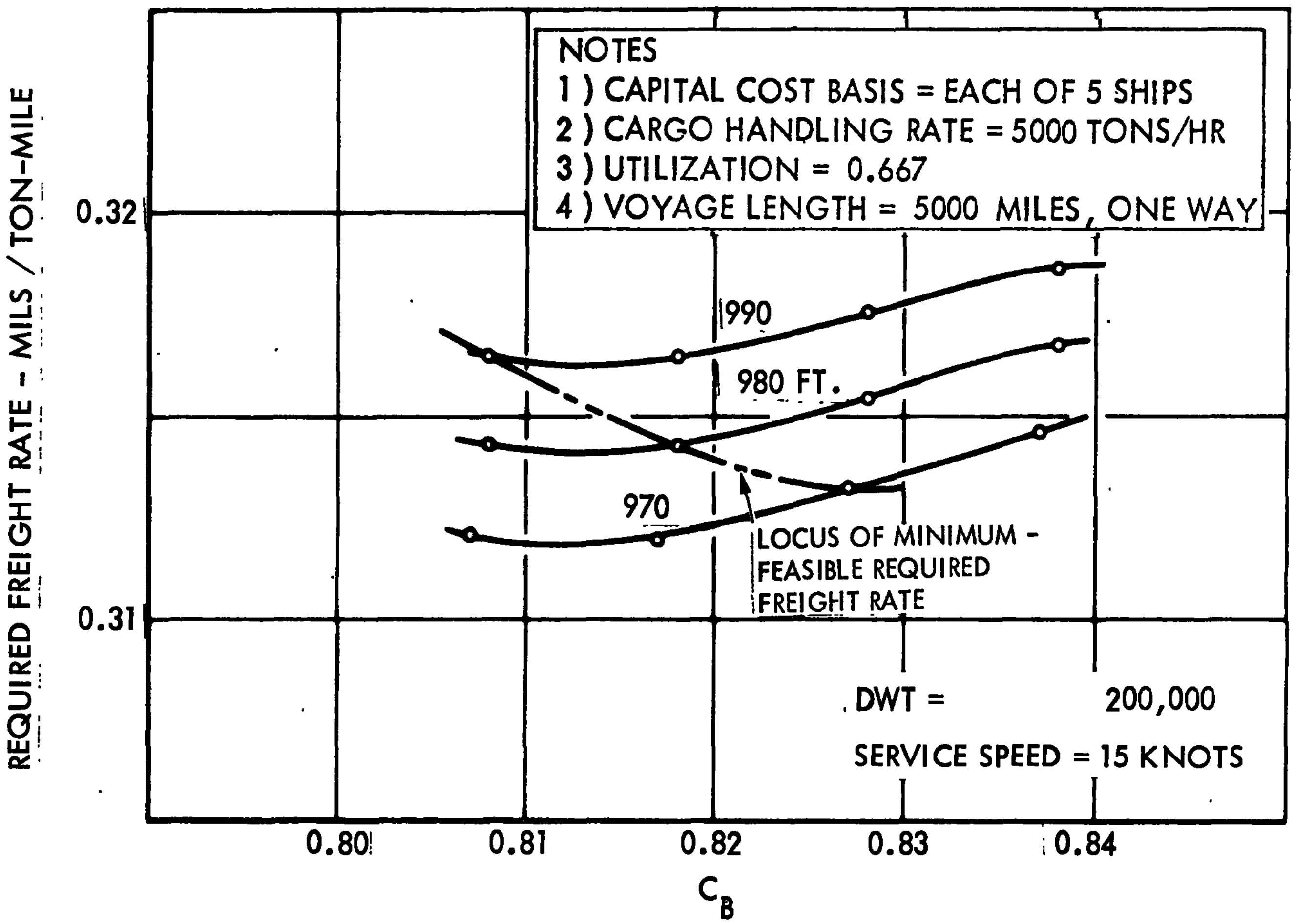


FIGURE 14 - REQUIRED FREIGHT RATE VS. BLOCK COEFFICIENT FOR 200,000 DWT, SERVICE SPEED 15 KNOTS

FIG. 15

FLOODABLE LENGTH CURVE

PROPOSED
60,000 D.W.T. / 35 FT. DRAFT
BULK CARRIER

NOTE:
MARGIN LINE IS
3" BELOW UPPER DECK

SCALE 1" = 37'-0"

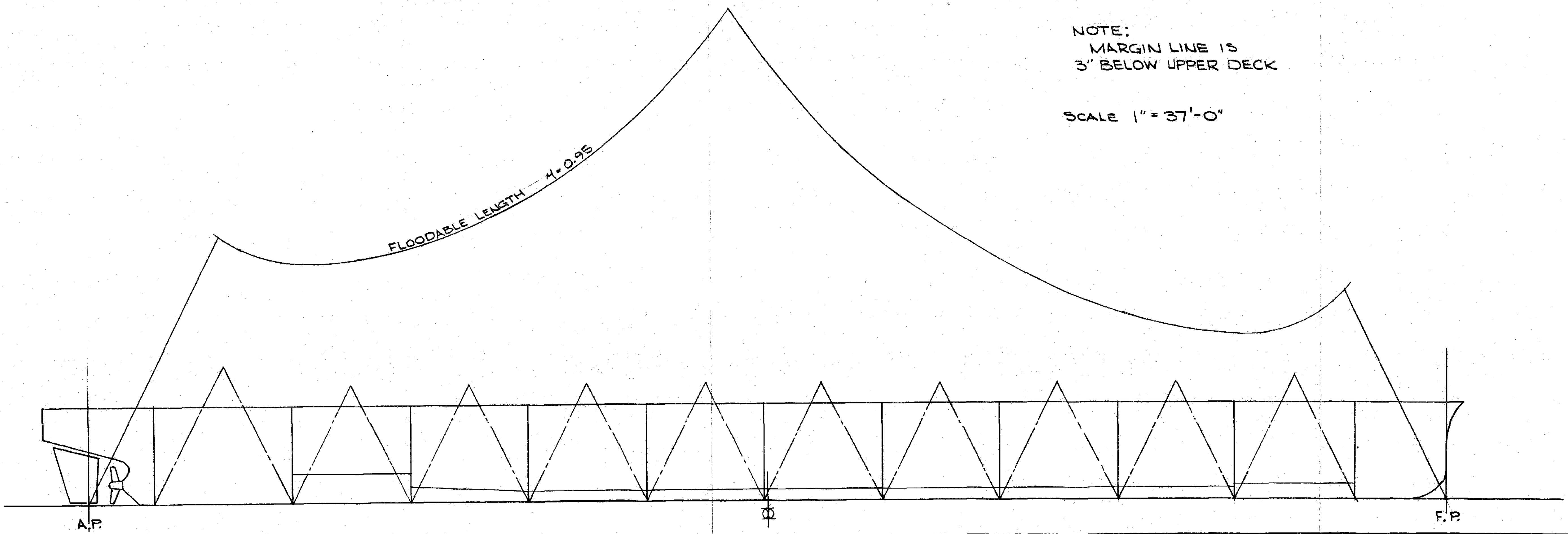


FIG. 16

FLOODABLE LENGTH CURVE

PROPOSED
125,000 D.W.T. / 45 FT. DRAFT
BULK CARRIER

NOTE:
MARGIN LINE IS
3" BELOW UPPER DECK

SCALE 1" = 46'-0"

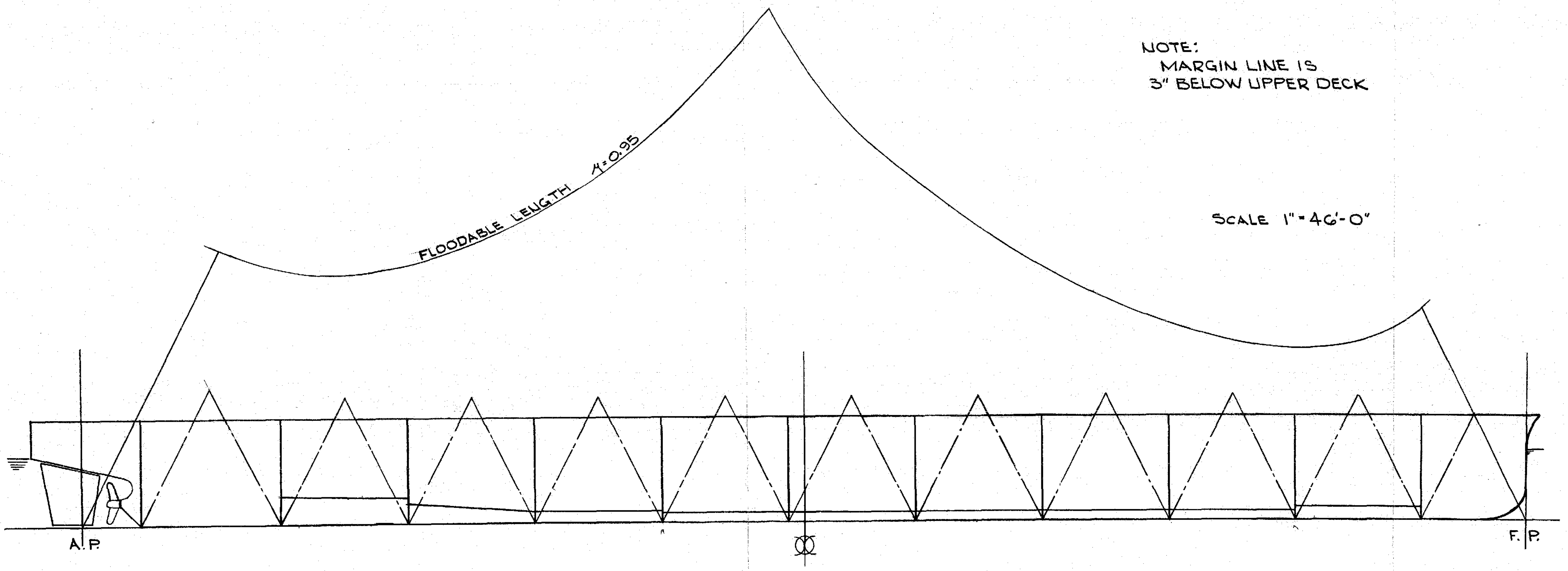


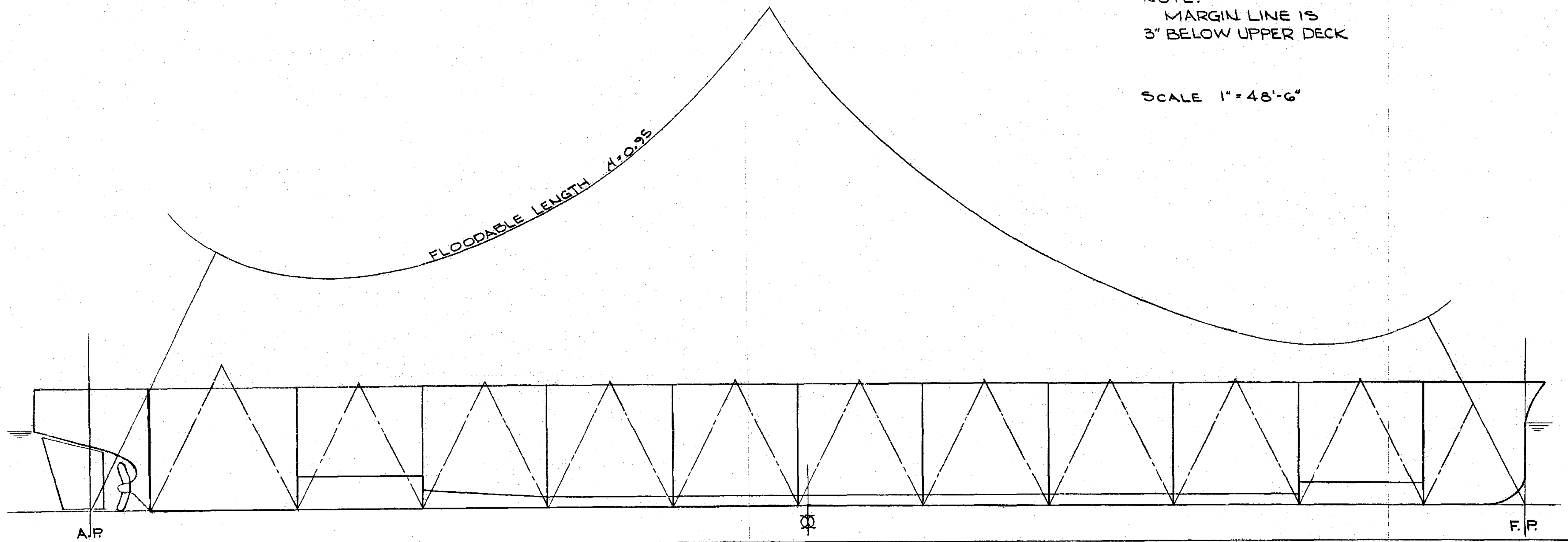
FIG. 17

FLOODABLE LENGTH CURVE

PROPOSED
200,000 DWT / 55 FT. DRAFT
BULK CARRIER

NOTE:
MARGIN LINE IS
3" BELOW UPPER DECK

SCALE 1" = 48'-6"



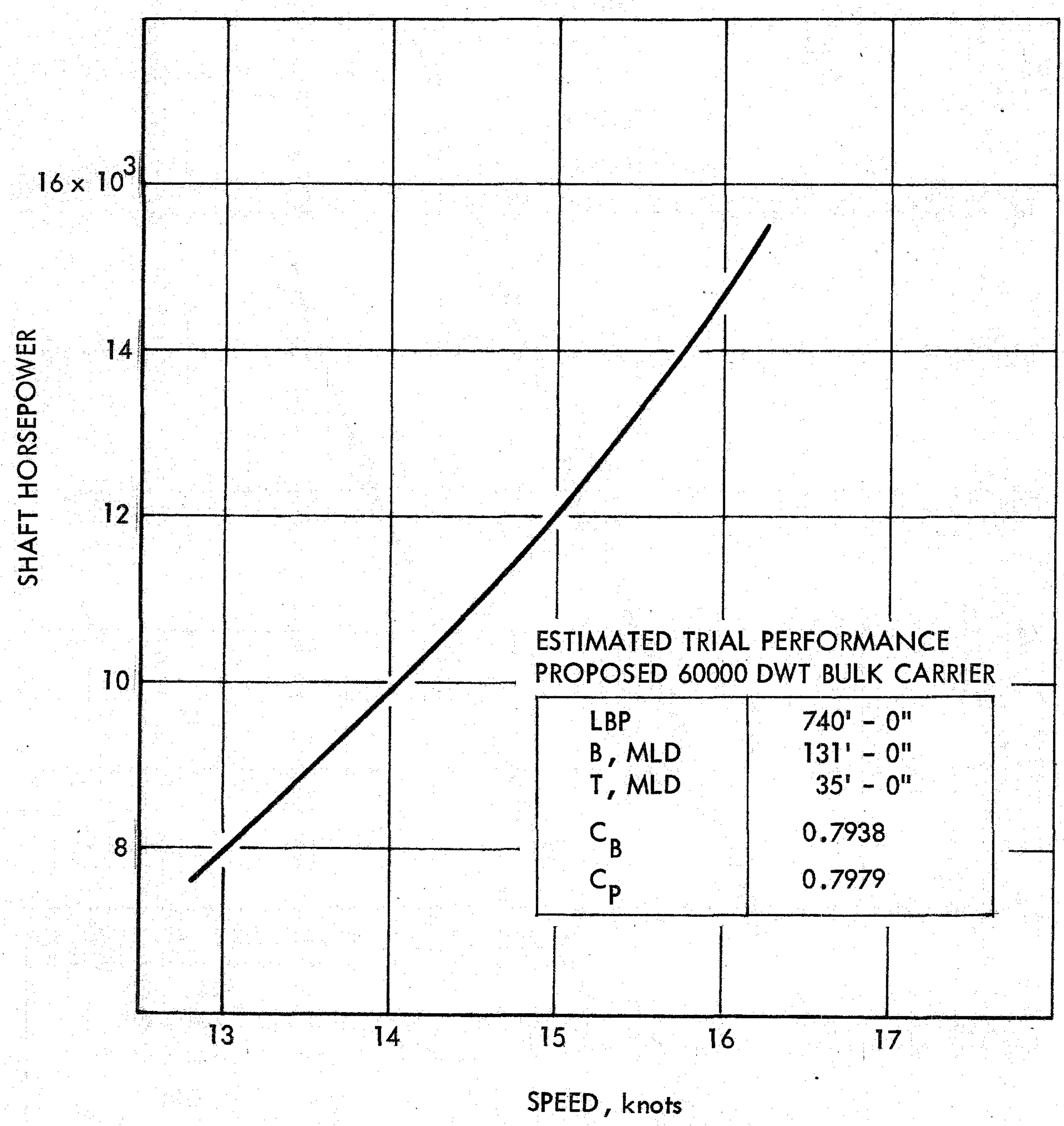


FIGURE 18 - ESTIMATED TRIAL PERFORMANCE PROPOSED 60,000 DWT BULK CARRIER

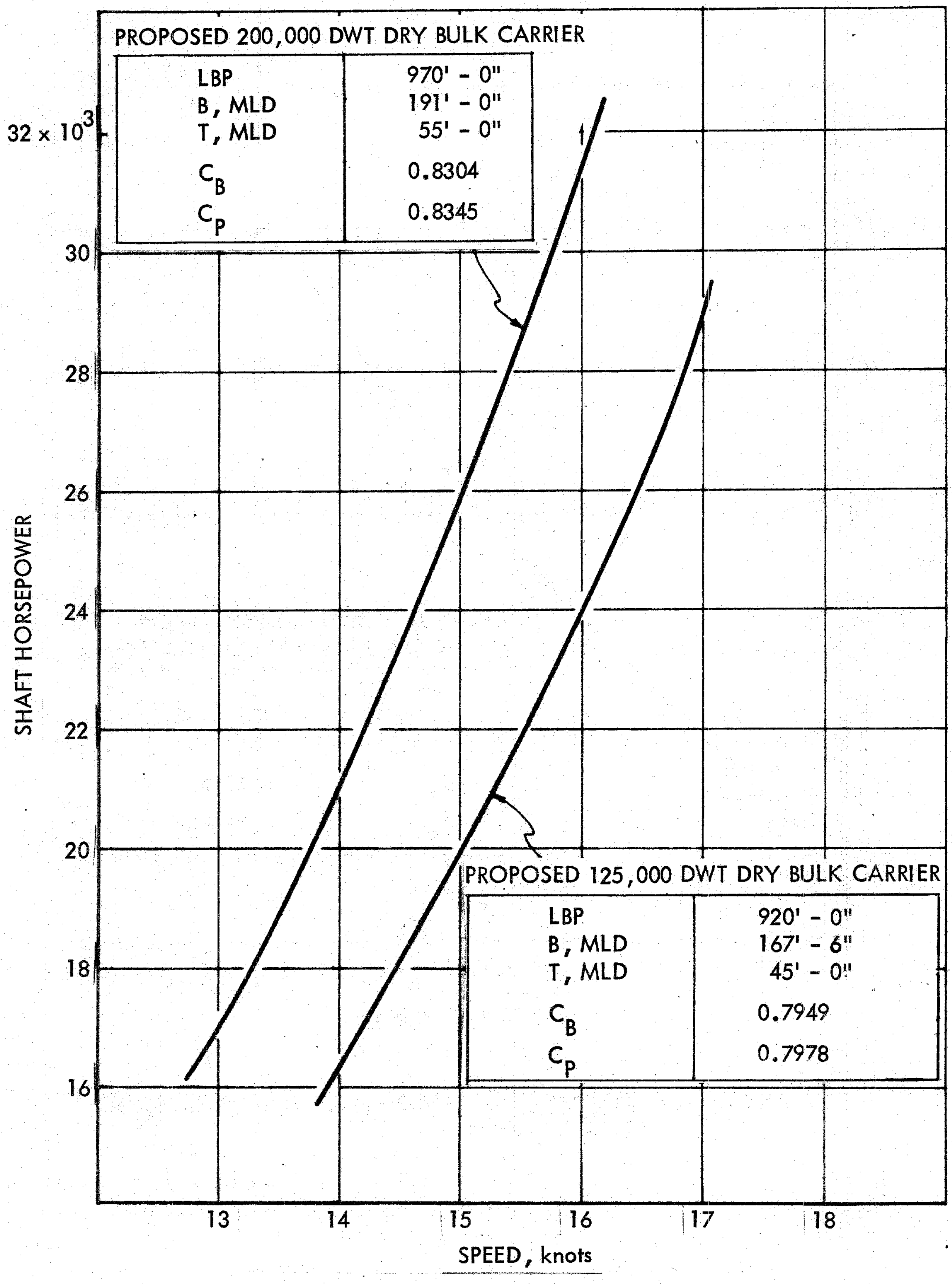


FIGURE 19 - ESTIMATED TRIAL PERFORMANCE

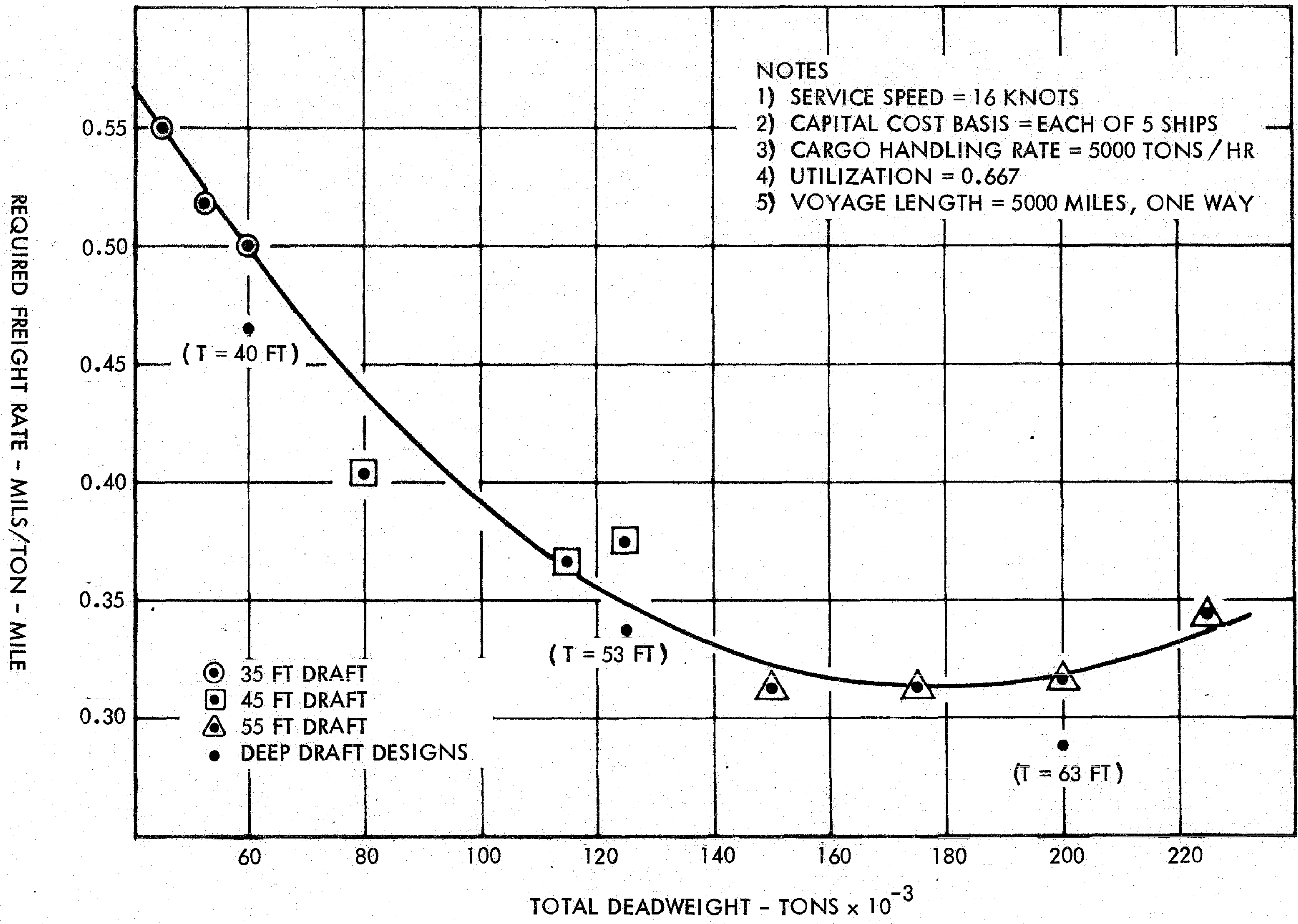
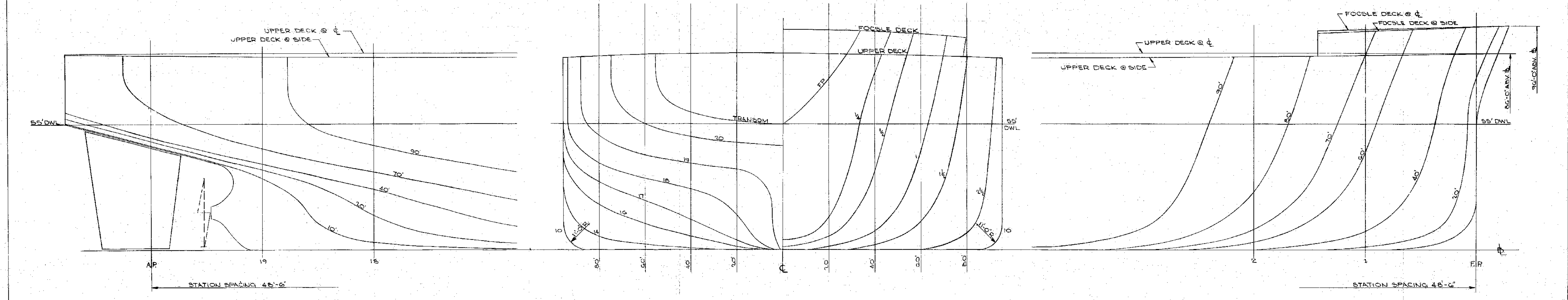


FIGURE 20 - REQUIRED FREIGHT RATE VS. TOTAL DEADWEIGHT



PRINCIPAL CHARACTERISTICS

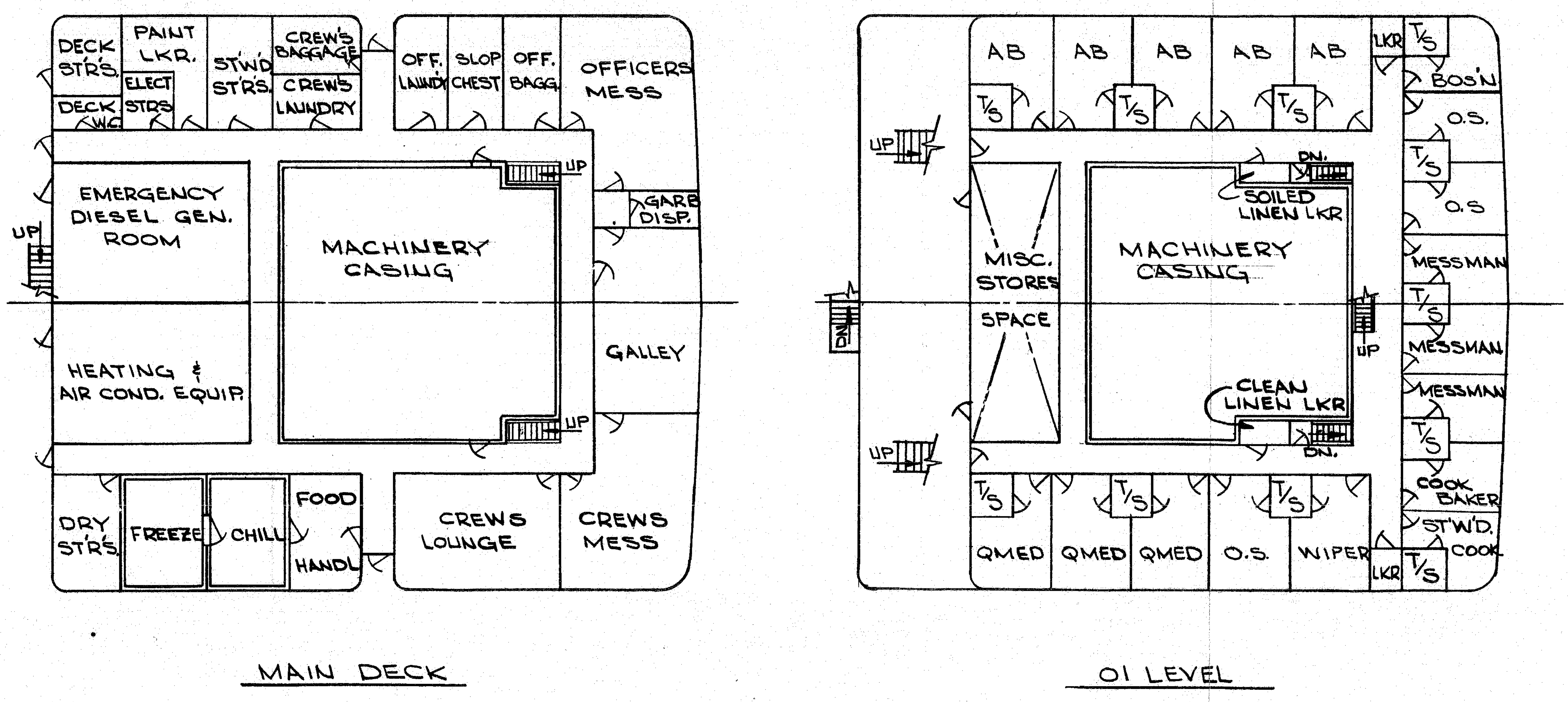
LENGTH B.P.	970'-0"
BREADTH, MLD.	191'-9"
DEPTH, MLD.	84'-0"
DRAFT, DESIGN MLD.	55'-0"
C_B	0.8304
C_P	0.8345

DWG. NO. 7330-301

HYDRONAUTICS, INCORPORATED

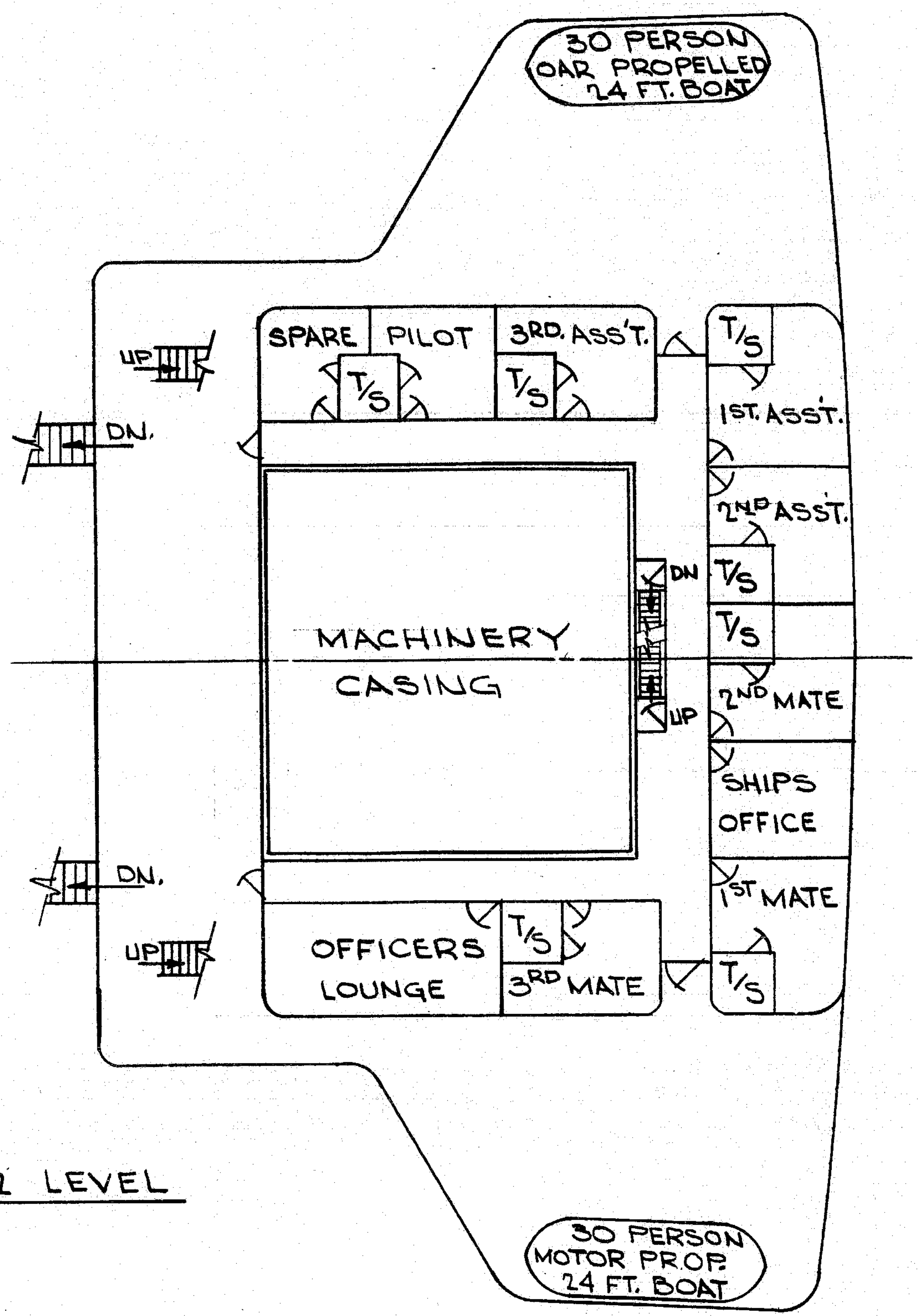
LINES PLAN
PROPOSED
200,000 DWT. / 55 FT. DRAFT
BULK CARRIER

DESIGNED	DATE	PROJECT ENGINEER H. LAIN	DATE 7-27-73
DRAWN G.W. PETERS	8-15-73	APPROVED	
CHECKED		APPROVED	8/31/73
CONTRACT NO.	JOB NO. 7330	DWG. NO. 7330-301	
SCALE 1"=10'-0"	SHEET OF SHEETS		

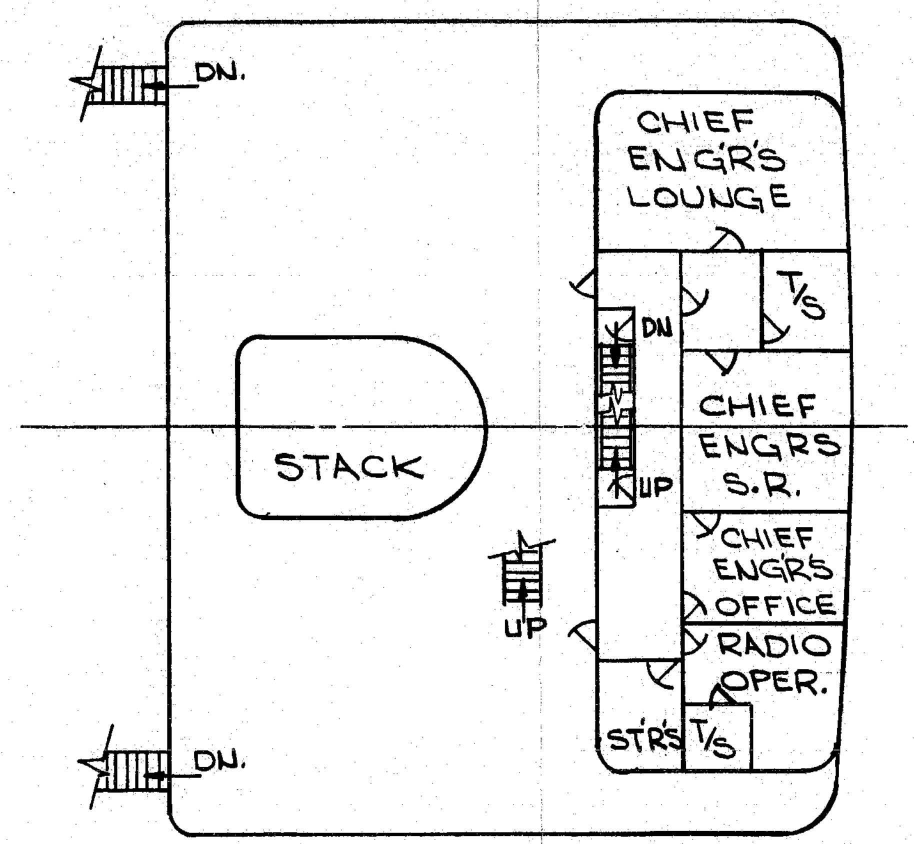


SCALE 1/16" = 1'-0"

DWG. 7330-108
SHEET 1 OF 3



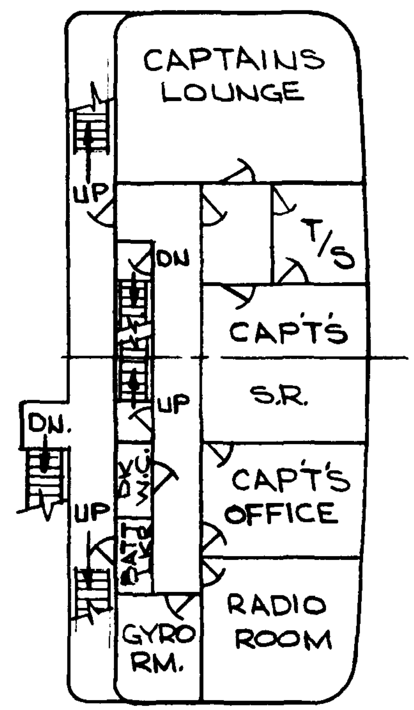
02 LEVEL



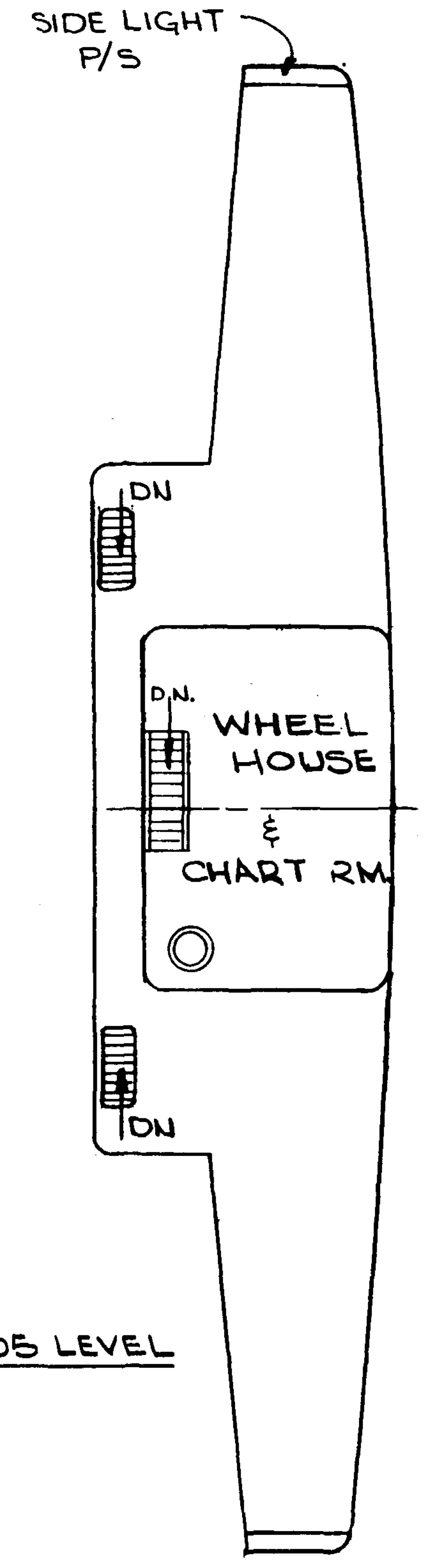
03 LEVEL

SCALE 1/16" = 1'-0".

DWG 7330-108
SHEET 2 OF 3



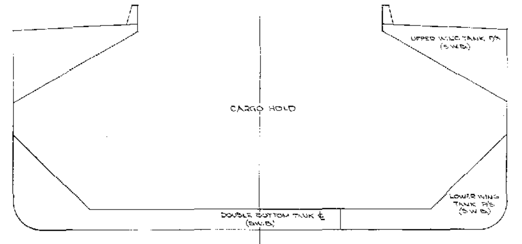
04 LEVEL



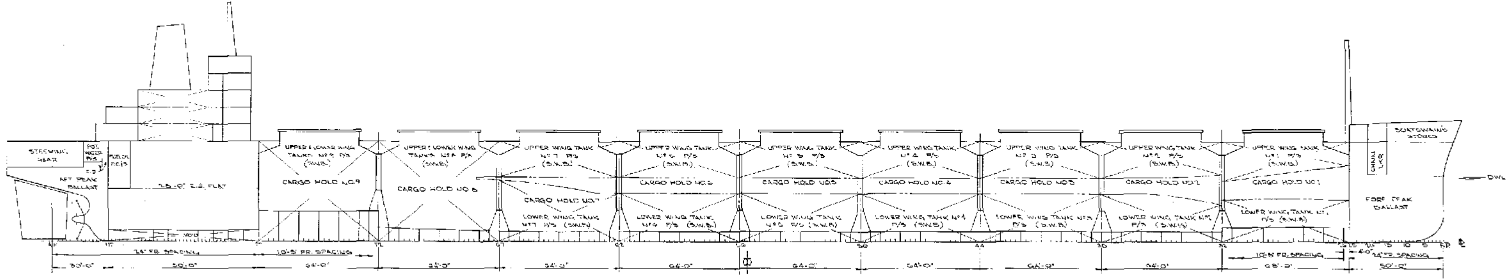
05 LEVEL

SCALE 1/16" = 1'-0"

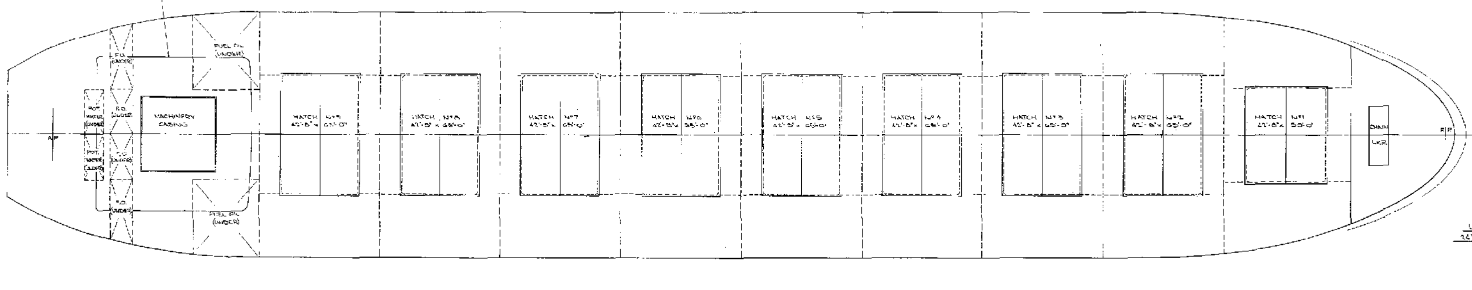
DWG. 7330-108
SHEET 3 OF 3



OUTLINE SECTION
THROUGH TYPICAL CARGO HOLD
SCALE ⅛" = 1'-0"



PROFILE



UPPER DECK
12" CAMBER NO SHEER

PRINCIPAL CHARACTERISTICS

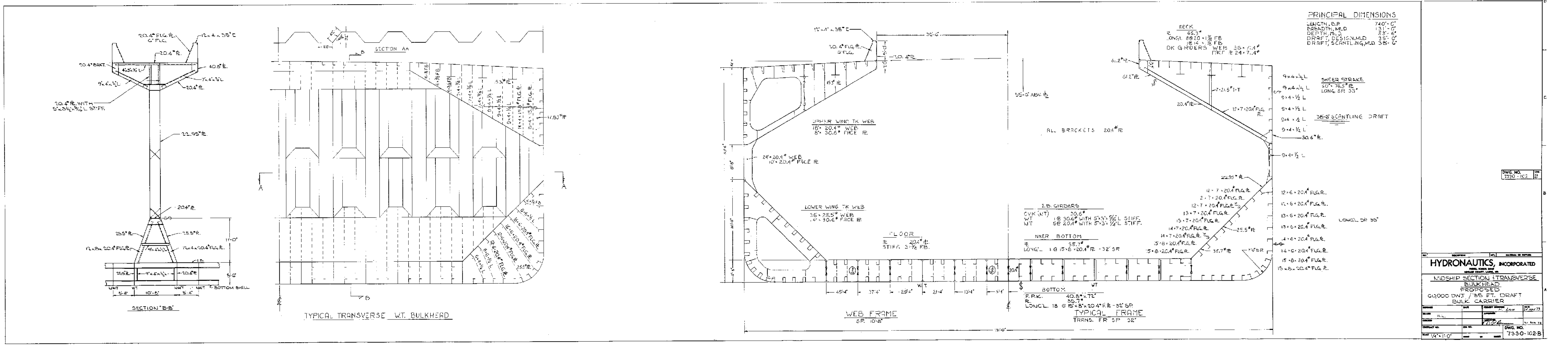
LENGTH, B.P.	740'-0"
BREATH, MLD.	13?'-0"
DEPTH, MLD.	53'-6"
DRAFT, MLD.	35'-0"

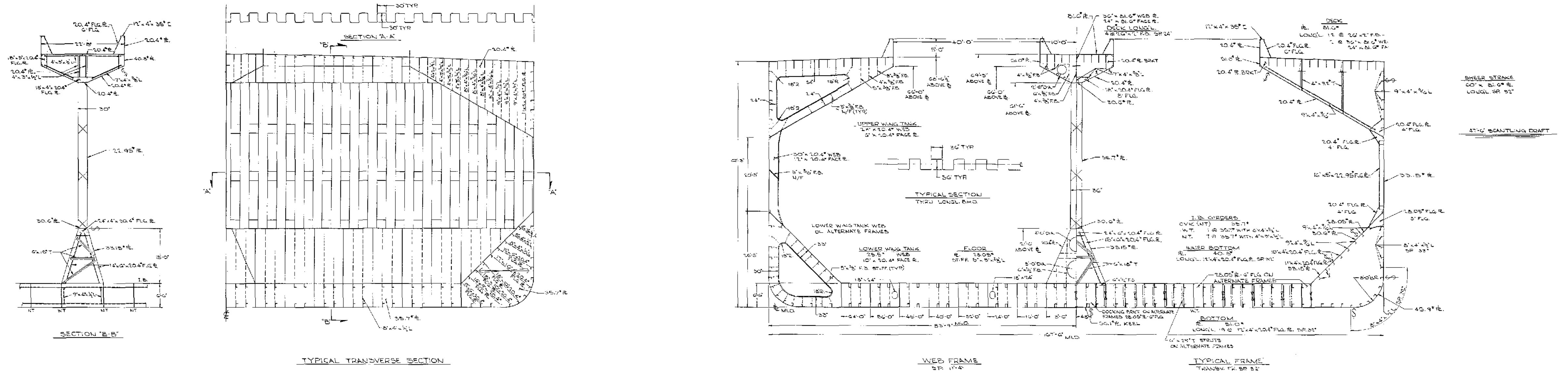
DWG. NO. 7330-103

HYDRONAUTICS, INCORPORATED

OUTLINE ARRANGEMENT
PROPOSED
60,000 DWT/ 35 FT. DRAFT
BULK CARRIER

PROJECT ENGINEER: H. LAIN — DATE: 7-26-73
DRAWN: J.A. HICKEY — 6-15-73
APPROVED: [signature] — 6/30/73
JOB NO. 7330
SCALE: 1/16" = 1'-0"
DWG. NO. 7330-103


SECTION "B-B"
TYPICAL TRANSVERSE W.T. BULKHEAD
SECTION AA
WEB FRAME
SP. 10'-8"
TYPICAL FRAME
TRANS. FR. SP. 32"
UPPER WING TK WEB
LOWER WING TK WEB
ALL BRACKETS 20.4# ℞
FLOOR
INNER BOTTOM
BOTTOM
DECK
SHEER STRAKE
38'-6" SCANTLING DRAFT
PRINCIPAL DIMENSIONS
LENGTH, B.P. 740'-0"
BREADTH, MLD. 131'-0"
DEPTH, MLD. 53'-6"
DRAFT, DESIGN, MLD. 35'-0"
DRAFT, SCANTLING, MLD. 38'-6"
HYDRONAUTICS, INCORPORATED
MIDSHIP SECTION & TRANSVERSE BULKHEAD
PROPOSED
60,000 DWT / 35 FT. DRAFT
BULK CARRIER
SCALE 1/4" = 1'-0"
DWG. NO. 7330-102-B



PRINCIPAL DIMENSIONS

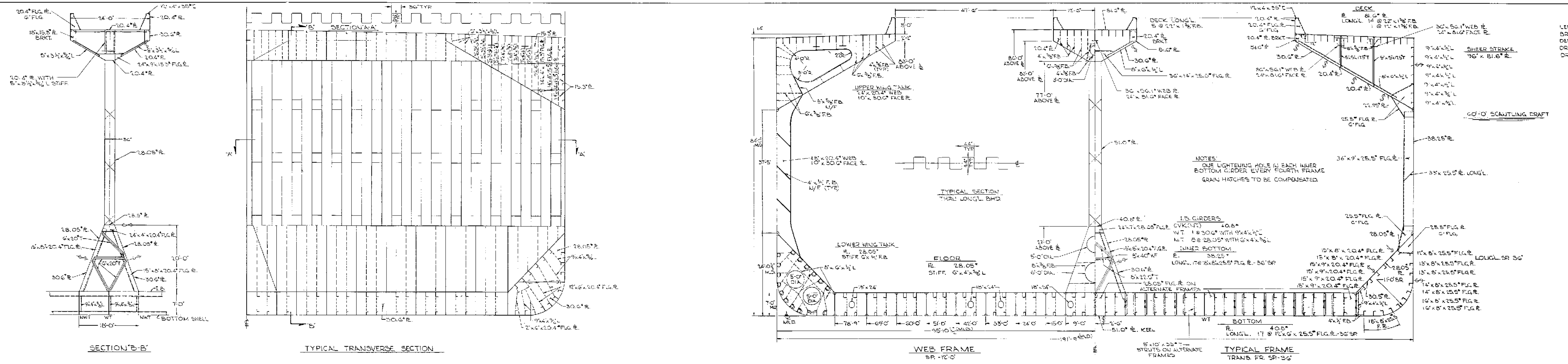
LENGTH, B.P.	920'-0"
BREADTH, MLD.	167'-6"
DEPTH, MLD.	67'-3"
DRAFT, DESIGN, MLD.	45'-0"
DRAFT, SCANTLING, MLD.	47'-6"

DWG. NO. 7330-202

HYDRONAUTICS, INCORPORATED

MIDSHIP SECTION & TRANSVERSE BULKHEAD
PROPOSED
125,000 DWT / 45 FT. DRAFT
BULK CARRIER

DRAWN: J.A. HICKEY	6-4-73	PROJECT ENGINEER: H. LAIN	DATE: MAY 73
CHECKED		APPROVED	31 AUG 73
CONTRACT NO.	JOB NO. 7330	DWG. NO. 7330-202	
SCALE 3/16" = 1'-0"	SHEET OF SHEETS		



PRINCIPAL DIMENSIONS

LENGTH, B.P.	970'-0"
BREADTH, MLD.	191'-9"
DEPTH, MLD.	84'-0"
DRAFT, DESIGN, MLD.	55'-0"
DRAFT, SCANTLING, MLD.	60'-0"

DWG. NO. 7330-302

HYDRONAUTICS, INCORPORATED

MIDSHIP SECTION & TRANSVERSE BULKHEAD

PROPOSED

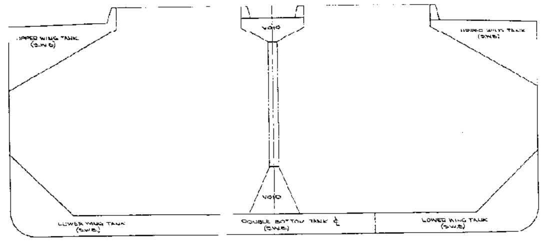
200,000 DWT / 55 FT. DRAFT

BULK CARRIER

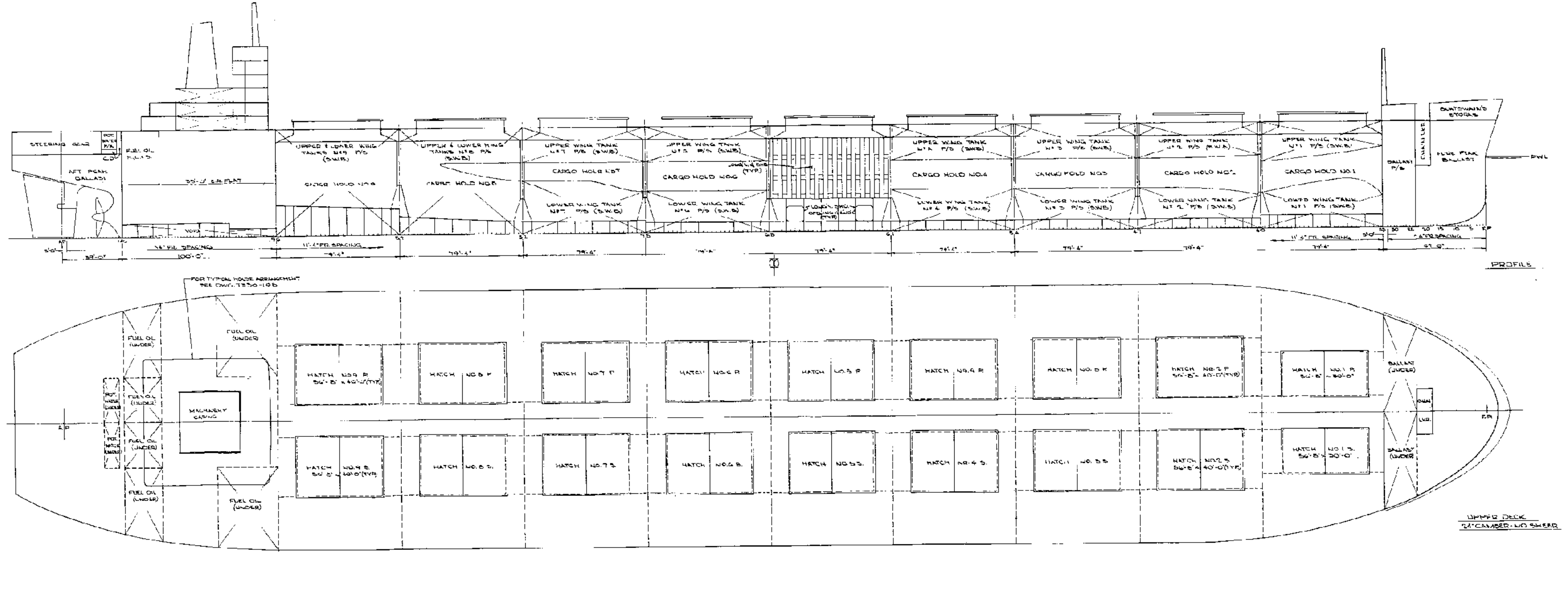
DRAWN J.A. HICKEY	6-7-73	PROJECT ENGINEER H. LANN	MAY 73
JOB NO. 7330		DWG. NO. 7330-302	
SCALE 3/16" = 1'-0"			

PRINCIPAL CHARACTERISTICS

LENGTH, B.P.	920'-0"
BREADTH, MLD.	167'-6"
DEPTH, MLD.	67'-3"
DRAFT, DESIGN, MLD.	45'-0"



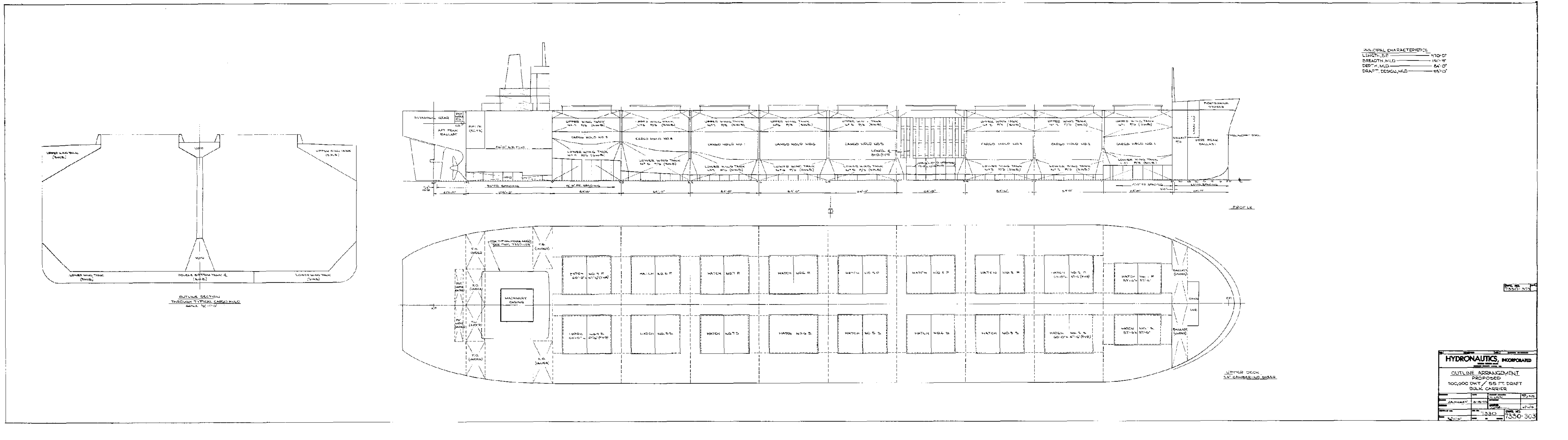
OUTLINE SECTION THROUGH TYPICAL CARGO HOLD
SCALE 1/8"=1'-0"



HYDRONAUTICS, INCORPORATED

OUTLINE ARRANGEMENT
PROPOSED
125,000 DWT / 45 FT. DRAFT
BULK CARRIER

J.A. HICKEY	6-15-73		7-26-73
SCALE 1/8"=1'-0"	7330	DWG. NO. 7330-203	


PRINCIPAL CHARACTERISTICS
LENGTH, B.P. — 970'-0"
BREADTH, MLD — 191'-9"
DEPTH, MLD — 84'-0"
DRAFT, DESIGN, MLD — 55'-0"
PROFILE
UPPER DECK
OUTLINE SECTION
THROUGH TYPICAL CARGO HOLD
UPPER WING TANK
LOWER WING TANK
DOUBLE BOTTOM TANK
VOID
CARGO HOLD NO. 1
CARGO HOLD NO. 5
CARGO HOLD NO. 6
CARGO HOLD NO. 7
AFT PEAK BALLAST
FORE PEAK BALLAST
STEERING GEAR
MACHINERY CASING
HYDRONAUTICS, INCORPORATED
OUTLINE ARRANGEMENT
PROPOSED
200,000 DWT / 55 FT. DRAFT
BULK CARRIER
J.A. HICKEY
6-15-73
7-2-73
7330
DWG. NO.
7330-303

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Restricted Draft
Bulk Carriers

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The development of restricted draft dry bulk carriers is recognized as a means for reducing transportation costs by permitting the operation of larger vessels out of existing ports. For three given drafts, a parametric computer design study of deadweight capacity and corresponding dimensions and form characteristics is carried out to determine maximum feasible (over)

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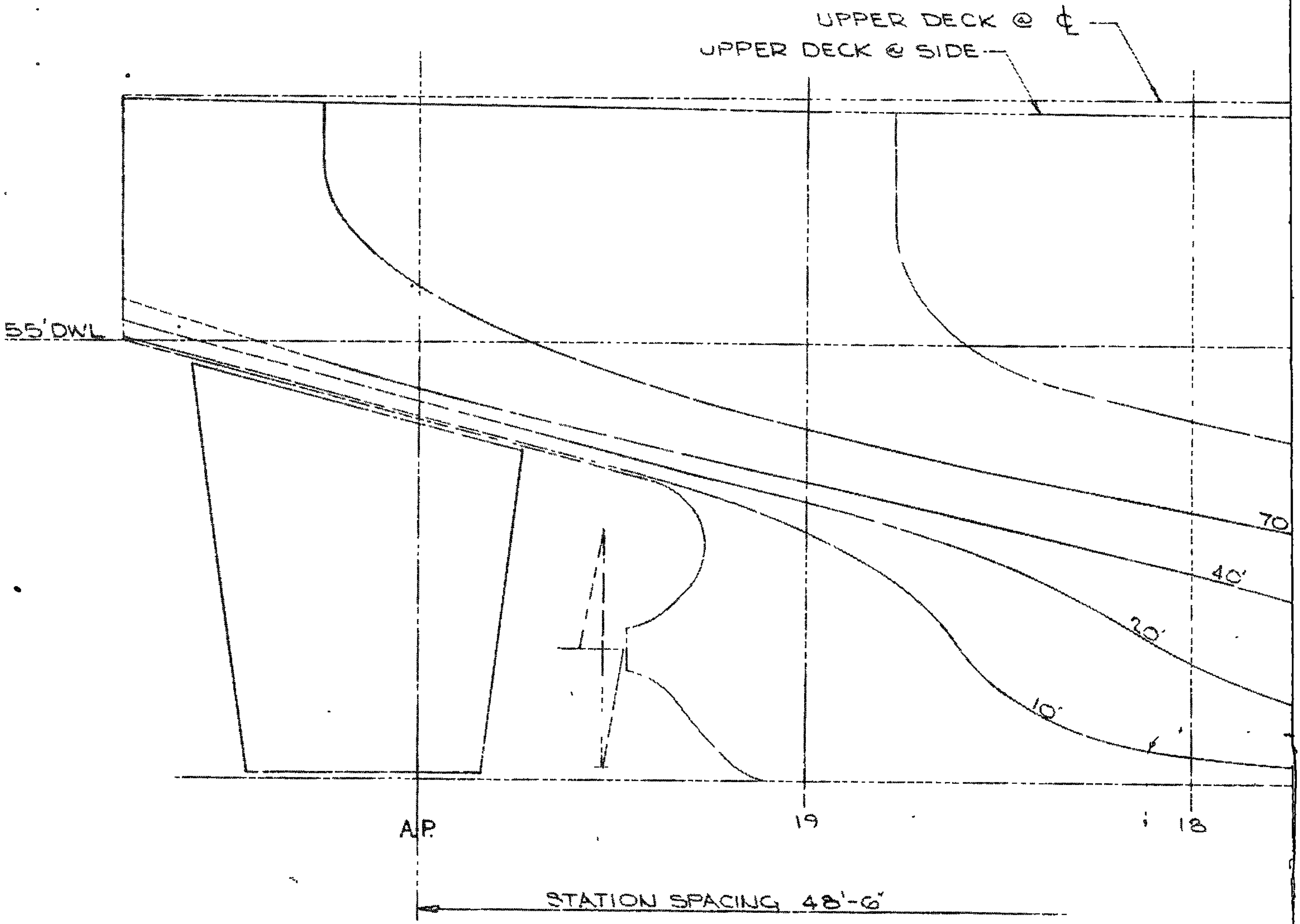
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) deadweight, subject to assumed physical boundary conditions and economic considerations. Restricted draft ship characteristics selected for the study are developed into concept designs by conventional design methods. The resulting characteristics and costs are compared with conventional deep draft vessel characteristics and costs. Finally, technical problem areas associated with restricted draft ship designs are recognized and discussed.


UPPER DECK @ ℄
UPPER DECK @ SIDE
55' DWL
70'
40'
20'
10'
A.P.
19
18
STATION SPACING 48'-6"