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THE ECONOMICS OF THE CONTAINER SHIP SUBSYSTEM

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by

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Abstract

Part I

The effects of a container operation on a traditional steamship company are discussed, and the need for planning emphasized. The "optimum" container ship is defined, and the naval architect's role in its determination is outlined. The two basic approaches to optimizing a system are described, and the limitations of each approach are stipulated.

Part II

An algorithm which estimates both capital and operating costs for container ships is presented, together with relationships for capacities, weights, and dimensions. (The computer program is appended.)

Part III

A typical algorithm output is presented, and its application to two basic types of optimization studies is described.

WHEN IN DANGER,
WHEN IN DOUBT,
RUN IN CIRCLES,
SCREAM FOR HELP!

A large portion of any success this report may encounter should be directed toward a number of people who assisted me greatly while I was developing it. Numerous shipping companies provided data on new or proposed container ships. Mr. John Ritter of States Marine Lines was especially helpful. Professor Harry Benford of The University of Michigan reviewed the paper, and arranged to have it published. Miss Mary Schnell edited the manuscript and effected many improvements. Mr. John Boylston of Sea-Land Service, Inc. was indispensable, providing both information and sound criticism.

I hope that those mentioned, and all others who had a hand in this paper, will accept my thanks. Their assistance made this paper possible.

Dave S. Miller
15 March 1968

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Nomenclature

All costs are in dollars; all weights are in long tons.

BEAM--(ft)

CABV--containers above deck (20-ft x 8-ft x 8-ft containers)

CAP--vessel container capacity (20-ft x 8-ft x 8-ft containers)

CB--block coefficient

CBEL--containers below deck (20-ft x 8-ft x 8-ft containers)

CCREW--annual crew cost

CDEN--container density (long tons per 20-ft x 8-ft x 8-ft container)

CFLT--shipyard bill for container ship fleet

CLHE--cost of labor for hull engineering

CLM--labor cost for machinery

CLO--cost of labor for outfit

CLST--cost of labor for steel hull structure

CM--material cost of machinery

CMR--annual cost of vessel maintenance and repair

CN--cubic number (ft³)

COHE--cost of materials for outfit and hull engineering

CONE--shipyard bill for a single vessel

CONT--one-way container flow per year (20-ft x 8-ft x 8-ft containers)

COWN--owner's costs during fleet construction

CP--vertical prismatic coefficient

CPS--cost per ship, including savings due to multiple ship construction

COHV--annual overhead cost per ship

COPER--operating cost per ship per year

CPTD--annual port costs (per day in port)

CPTV--annual port costs (per voyage)

CSTL--cost of materials for steel hull structure
CSTOR--annual cost of stores and miscellaneous
DEPTH--to main deck at side (ft)
DIST--round-trip voyage length (nautical miles)
DKAR--function of available deck area (ft²)
DRAFT--draft (ft)
DWT--vessel deadweight
EHP--effective horsepower (horsepower)
FCOP--annual fleet cost of operation
FREQ--frequency of service (days)
HMINS--annual cost of hull and machinery insurance
LBP--length between perpendiculars (ft)
LSW--light ship weight
MCN--modified cubic number (ft³)
MVL--the maximum voyage length which can be serviced by a
 given number of vessels operating at a given speed on a
 given frequency (nautical miles)
NCREW--crew size
NPORT--the number of times each ship is in port per year
NSHIP--the number of ships required to provide a given service
OHVD--overhead
PCOEF--propulsive coefficient, excluding an allowance for shaft
 losses
PINS--annual cost of protection and indemnity insurance
PFUEL--fuel consumption in port per ship per year (barrels)
PTIME--port time per round-trip voyage (days)
QUAN--one-way container flow per year (20-ft x 8-ft x 8-ft
 containers)
SAIL--number of sailings per year
SFUEL--fuel consumption at sea per ship per year (barrels)
SHP--maximum continuous shaft horsepower (horsepower)
SPDLG--speed-length ratio (KT / ft)
STIME--sea time per round-trip voyage (days)
STNCE--annual cost of crew subsistence
TCFLT--total cost of fleet, including owner's costs

TCLAB--total labor cost
TCMAT--total cost of materials
TCOST--total annual container ship subsystem cost
VK--normal sea speed of vessel (knots)
WABV--weight of containers above deck
WCONT--weight of containers
WCRST--weight of crew, stores, etc.
WFUEL--fuel weight
WMACH--machinery weight
FWWTR--feed water weight
WOHE--weight of outfit and hull engineering
WPWTR--potable water weight
WRINS--annual cost of war risk insurance
WS--weight of steel hull structure

Introduction

Containerized shipping is now in the midst of its "goldrush" period. Several operators' success has prompted competing firms to enter the container business, either lured by the prospects of greater profits or spurred by the "survival" implications of competition. As may be expected in such a dynamic situation, emphasis is on haste rather than thoughtful development. This is particularly true of the economic aspects of container ships, since little industry-wide research has been undertaken. It is this void that this paper hopes partially to fill.

"The Economics of the Container Ship Subsystem" is divided into three principal parts. Part I evolves the rationale required to optimize a container system. Part II, the "nuts and bolts" of the paper, describes a specific algorithm which may be used to determine container ship building and operating costs. Finally, Part III relates the prior sections to one another, and shows typical results.

PART I

THE RATIONALE

The Rationale

When a steamship operator investigates initiation of container service for a given route, he must ascertain three unknowns:

- (1) The demand for the service in containers per year (container flow)
- (2) The origin-to-destination* time requirements, both from customer and competitor standpoints
- (3) The probable revenue to be gained for providing such a service.

In reality, the three are interdependent, for a change in one parameter will cause changes in both of the others. All three boil down to: "What does the customer want?"

Eventually, through intuition, market research, ceiling-gazing, or any combination of these, the ship operator evolves a container flow-speed-revenue relationship. He then seeks to estimate his costs for providing each of the possible alternative services. Once such costs are obtained, they can be combined with the previously estimated revenues, and the ship operator can choose the alternative with the greatest potential profitability, or he may elect to drop the proposal altogether.

In estimating costs, however, traditional steamship companies confront several difficulties. They no longer face a one-mode (seaborne) transportation problem. Rather, three,

*Note that the origin-to-destination time is the total time that the containerized goods are in transit, as opposed to the pier-to-pier time.

and possibly four, modes are involved: sea, land, terminal,* and air. Stated alternatively, in the course of a given trip, a container may travel by ship, truck, train, barge, terminal, and possibly, though not probably, plane.** Suddenly, "speed" is no longer measured in voyage time plus turnaround time, and "cost" is no longer the sum of ship depreciation, ship operation costs, and terminal handling-costs.

Thus, to handle the more sophisticated planning required for the multimode container system, the traditional ship operator must change drastically. The erstwhile "shipping" company must transform itself into a "container shipping company." Two changes must take place:

- (1) Management at all levels must think in terms of "containers" and the overall systems, rather than in terms of "ships."
- (2) The importance of planning must be emphasized, and, through internal growth or increased reliance on outside consultants, planning capabilities must be increased.

It could be argued that, if a given steamship company has no intention of providing a complete container service, such as Sea-Land Service, Inc., that it need not consider the nonsea modes discussed earlier. This, on the surface, seems valid. Yet, several questions arise: How can the company in question successfully integrate its services with those of shore-bound container organizations (i.e., trucking firms, railroads, or terminal facilities) if it cannot understand the

*A container is in the terminal mode when it is in the process of switching between modes, or between elements of the same mode. The terminal mode is a legitimate transportation mode because, while little actual movement is involved, great quantities of time may be consumed while the container sits idle, awaiting further movement.

**The air mode will be omitted from all further discussion.

problems such cooperation entails? Unless such cooperation is obtained, how can the shipping company compete with firms making more effective use of the land modes, especially "captive" container organizations? Also, assuming that adequate shore connections can be made, can the shipping organization leave itself to the mercy of its shore-bound partners, without some planning capability to constantly reevaluate its competitive position?

Clearly, any shipping firm seriously in the container business must be able to analyze the entire container flow system.* Containers are not a seaborne proposition!

Note that throughout the preceding discussion of planning for container operations, ships have received no special emphasis. The implication of this is obvious: a fleet of container ships is a subsystem whose existence is justified only by the presence of a flow of containers over a given sea route. That the container is the primary cargo-carrying medium cannot be questioned. The container is the only element of the system common to all transport modes, and is the only element in direct contact with the cargo throughout its movement through the system.

Consequently, a container ship is a secondary means of cargo transport. As such, it is subject to, rather than dominant over, container flow patterns. The management of container shipping companies must look upon container ships as petroleum company managers look upon their tankers: "We don't like to pay for them because we can't sell them, but we need them to stay in the damn business." Let us consider the tanker-container ship analogy in detail, for the number of parallels is striking.

*This need is further supported by several shipping companies presently in the container business who are absorbing significant losses. Invariably, they were, several years ago, guilty of "leaping before they looked."

The primary business of a petroleum company is to sell refined products, not operate tankers. This is reflected in the company's annual statement: tankers represent only a small part of the oil company's total investment and consume only a small portion of the company's operating revenue.

Similarly, a container shipping company is primarily concerned with selling the use of their containers to customers, or moving containers belonging to customers. Their ships, while representing a sizable percentage of the total investment, might constitute less than half of this investment. Containers, terminals, and perhaps trucks, represent significant capital expenditures.*

Consider the procedure an oil company goes through when choosing the means of supplying a given new refinery with crude oil. In their efforts to provide a constant, yet inexpensive, flow of crude oil into the refinery, the petroleum company managers are confronted with numerous possibilities. A refinery in Rotterdam using Near East crude oil might consider the following:

- (1) A pipeline from oilfield to refinery
- (2) Several large tankers combined with large storage-tank capacities at both ports-of-call
- (3) Many small tankers combined with small storage-tank capacities at both ports-of-call
- (4) A constant flow of tank cars traveling by rail between both points
- (5) Combinations of the above.

*Container shipping companies may make agreements with trucking concerns, port authorities, or other shore-bound enterprises, eliminating many capital expenditures. This is the equivalent of an oil company chartering tankers. In any event, any such long-term agreement is a financial commitment having many similarities to capital investment (1), and could be considered "implicit" capital investment.

How, then, is a decision reached? First, some alternatives are discarded because of "judgment" considerations. Such considerations might include:

- (1) Freedom from interruption of crude oil flow due to changes in the political climate of the countries involved
- (2) Adequate continuation of crude oil supply when one unit of the transportation system is disabled.

The list of such factors is infinite, and their application to the prior list of alternatives is obvious.

The next step is to call in specialists, as needed, to provide cost estimates for each remaining alternative. Experts would work together on multimodal proposals. In this situation, the naval architect would be responsible for outlining ship requirements and preparing ship cost estimates. These would then be combined with shore storage facility* costs, and the costs for each tanker alternative determined.

Finally, a decision can be made on the best alternative. In this case, the best alternative is the one that possesses the highest--or lowest--merit rating,** after those unacceptable because of "judgment" reasons have been dropped. If the decision is to build a given fleet of tankers, the naval architect is again needed. He now has the task of designing the best, or optimum, fleet of tankers compatible with the overall system specified. Hence, the decision-making process, with judgment and cost criteria, begins anew, though this time within the naval architect's sphere of influence, in the detailed design of the required tankers.

*Tank farms

**The criterion used to rank the alternatives: discounted cash flow rate of return, net present value, present worth, average annual cost, etc.

To summarize the preceding decision-making process, we have the following steps, in order:

- (1) Establish system requirements
- (2) List alternatives available
- (3) Eliminate alternatives that fail to satisfy judgment criteria
- (4) Prepare cash flow estimates for remaining alternatives and select the alternative with the highest (lowest) measure of merit
- (5) Repeat procedure for each subsystem of the chosen system, eventually leading to a detailed system design.

It should now be apparent that the procedure described for designing a crude-oil delivery system is precisely that which should be applied to the design of a container system. Variables that would lead to differing alternatives would be:

- (1) Container flow rate
- (2) Delivery time requirements
- (3) Differing combinations of transport modes.

Relevant judgment considerations might include:

- (1) Design flexibility for service on other routes
- (2) Adequate allowance for future increases in the container flow.

At this point, the talents of land transportation specialists, terminal analysts, and naval architects can be combined to provide cost estimates for each component of each alternative container system. The four basic components would then be:

- (1) A set of containers
- (2) The appropriate land transport capability (trucks, bogies, etc.)

- (3) The appropriate sea transport capability (ships, barges, etc.)
- (4) The appropriate intermodal capability (terminals, marshaling yards, etc.).

Once such estimates have been prepared, a measure of merit can be applied to determine the optimum container system. The optimum container system, in turn, indicates the optimum container ship subsystem. Hence, the optimum container ship may now be defined as the most economical container ship that will, when operating as a part of a fleet of similar ships, provide the container movement specified by the optimum container system. This implies that a suboptimized container ship subsystem may be required to yield an optimum container system, and this is indeed the case.

Finally, the naval architect's responsibilities in the development of the optimum container system fall into two major categories:

- (1) The naval architect must prepare cost estimates for the seaborne-mode components of all proposals, and must assist in the evaluation of these proposals.
- (2) The naval architect must design the most economic fleet of ships which will satisfy the requirements dictated by the optimum container system.

Several comments should be directed at the choice of an appropriate measure of merit for determining the optimum container system or container ship subsystem. Two general alternatives are available. You can attempt to optimize a system by: (1) maximizing the profitability or net present value of the entire system, or (2) minimizing the cost of each subsystem in the system. Both approaches will be considered, in turn, and it will be shown that the second alternative--minimizing costs--is valid only in certain instances.

Obviously, maximizing the overall system profitability is the superior approach, because it alone provides an estimate of rate of return on investment that a proposed container system will yield. This is demonstrated by considering an extreme case: It is possible to construct a system of minimum-cost subsystems, only to discover that the resultant system, for all of its "optimum" virtues, still loses money. Maximizing system profitability, then, is the only approach that takes into account expected revenues.

Maximizing the system's level of profitability requires estimates of the following:

- (1) The total revenue generated by the system
- (2) The investment required by each element of the system
- (3) The annual direct operating cost of each element of the system.

Comparisons of alternative systems are readily accomplished by the calculation of one of the following measures of merit:

- (1) Discounted cash flow rate of return
- (2) Present worth or net present value.

If adequate attention is given to possible differences in life spans, patterns of returns, and before- and after-tax profit levels, a meaningful estimate of probable returns can be made (2).

Note that it is also possible to select an optimum container system on the basis of the average annual cost (AAC) or required freight rate (RFR) criteria defined by Benford (2). Both approaches have the advantage of not being dependent on revenue estimates. However, neither do they provide an indication of a system's probable profitability level. Hence, I do not favor them. In any event, both AAC and RFR require the same information as maximizing system profitability, with the exception of revenue projections.

Frequently, though, the scope of a given economic study may be limited, and hence, the study may not provide all of the information required to estimate the level of profitability. In this situation, optimizing the system by minimizing subsystem costs appears attractive. As it develops, this approach can be quite useful, but only if care is exercised in the choice of interest rates.

Unless the interest rate used in the subsystem analysis is approximately ($\pm 2\%$) equal to the level of profitability of the overall system, a skew will be introduced into the minimum cost studies. Thus, if a system is earning at a rate of 16 percent,* and if an assumed interest rate of 10 percent is used in a container ship minimum-cost study, then over-designed, high-cost ships will be favored, and the resultant container ship subsystem will actually lower the profitability level of the overall container system. Hence, it is imperative that the system's rate of return on investment be used as the discounting rate in minimum-cost studies.

The information required to minimize the cost of the container ship subsystem, then, is:

- (1) The overall, before-tax rate of return on investment of the parent system
- (2) The investment required to obtain the requisite container ships
- (3) The direct annual operating costs of these container ships.

Comparisons of alternative subsystems can thus be accomplished by comparing either: (1) the average annual cost (operating plus capital recovery), or (2) the required freight rate (average annual cost reduced to cost per container carried).

*Both percentages (16 and 10) are after-tax rate of return.

Each approach--either maximizing system profitability or minimizing subsystem costs--is uniquely suited to one of the two general situations encountered. A company investigating a new container service would be obliged to do a thorough analysis of the proposed service, and estimate an overall system level of profitability. However, since no system presently exists over the proposed route, analysis of subsystems is impossible.

On the other hand, a container shipping company may seek to increase the overall container system's level of profitability by refining the operation of an existing system. Hence, since the system's interest rate of return is known, the minimum-cost approach can be readily employed. Note, however, that minimum-cost studies made at a later date should use system interest rates that reflect the increases due to prior refinement of subsystems. Normally, an annual calculation of the system's overall interest rate of return on investment will provide an interest rate suitable for use in minimum-cost studies.

PART II

THE "NUTS AND BOLTS"

The "Nuts and Bolts"

The information presented in this section is intended to be used in determining the optimum container system. An algorithm is presented which estimates the cost of the container ship subsystem for various service requirements, and which also provides the data required for the design of an optimum container system.

However, my intent is not to generate a voluminous set of curves that define the optimum container ship for every situation and circumstance. Differences throughout the industry in building locations (foreign and domestic), operating practices and discounting rates, for example, render this impossible. Rather, the algorithm is intended as a planning tool that can readily be adapted to any given company's needs. To this end, the algorithm is described in considerable detail.

The algorithm is, as may be expected, performed by computer and can easily be translated into any of several languages. The entire program, with the exception of the Taylor Series subroutine used to estimate effective horse-powers, is presented in the Appendix. Presently it is written in the MAD (Michigan Algorithmic Decoder) language, as used at The University of Michigan.

Basic Ship Parameters

Inputs for the program are representative of current practice in container ship design. A 20-ft x 8-ft x 8-ft container size was chosen simply because most of the new

ships used in developing the algorithm were designed for this particular van. It is important to note that 22 of the 25 ships used are "new" designs. Thus, the program reflects current design trends for container ships.

Only four of the ships considered rely on permanent ballast. Hence, again reflecting current trends, ships "designed" by the program carry no permanent ballast. This introduces the possibility, particularly in the lower speed-length ranges ($V/\sqrt{L} < .65$), that a ballasted ship might be more economical than the equivalent nonballasted ship. In my opinion, this is improbable. To pay \$80 per installed ton of drilling mud (approximately \$400,000 for a \$7.5 million dollar ship) initially, and then to haul the mud about for twenty years seems wasteful.

Still, the possibility exists. Hence, it is relevant to note that any skew resulting from the deletion of ballasted ships will be minimized by the characteristic behavior of fine hull forms in low speed-length ratio ranges. Consider a ship operating at $V/\sqrt{L} = 0.65$. The recommended block coefficient for a ship so driven is in the neighborhood of 0.70, while most pure container ships will have block coefficients around 0.60. Hence, a discrepancy exists even at this point. However, Taylor (3) states that, at this speed-length ratio, resistance decreases as the block coefficient decreases. Thus, credit, in terms of reduced horsepower, crew, and fuel requirements, will be assigned to the finer nonballasted hull forms. This will, in turn, narrow the cost discrepancy in any overall cost studies. The absence of nonballasted ships, then, can be in large part disregarded.

The program consists basically of four interative loops, through which frequency of service, number of containers moved

in either direction per year (container flow), ship speed,* and round-trip voyage length are systematically varied. The limits presently applied to each of these variables are shown in Table 1. Obviously, these values may be adjusted to suit any specific route or situation.

Given a set of these four variables, it is possible to calculate the number of ships required to provide the service, and the required container capacity of each ship. Fifty-one sailings per year are assumed for weekly service; one sailing is assumed to be missed for overhaul. Similarly, 25 sailings are assumed to constitute biweekly service, and 16 1/3 sailings per year are taken as a triweekly schedule. (Note that any number of ships can be rotated through a maintenance schedule in the weeks following the "dropped" sailing.) The ship's required capacity is then:

$$\text{CAP} = \text{CONT} / \text{SAIL}$$

where CAP = ship's required capacity in 20-ft x 8-ft x 8-ft containers

CONT = one-way container flow per year (20-ft x 8-ft x 8-ft containers)

SAIL = number of sailings per year.

Port time per voyage is now easily estimated. Assuming two cranes and a loading cycle time of four minutes (15 containers loaded and unloaded per hour), and allowing six hours for entering and leaving port,

$$\text{PTIME} = 2 \times \left[\text{CONT} \left(\frac{\text{hour}}{30 \text{ containers}} \right) \left(\frac{\text{day}}{24 \text{ hours}} \right) + .25 \text{ days} \right]$$

where PTIME = port time per round-trip voyage in days.

Note that a service allowance may readily be inserted, if desired.

*Sea speed used is the Maritime Administration's "normal sea speed," defined as the speed attained on trials at 80 percent of the maximum continuous shaft horsepower.

Table 1
Limits of Major Variables

Variable	Lower Value	Increment	Upper Value	Abbreviation
Frequency of service (days)	7	7	21	FREQ
Container flow per Year (20-ft x 8-ft x 8-ft containers)	10,000	10,000	40,000	QUAN
Normal sea speed (knots)	12	3	27	VK
Round-trip voyage length (nautical miles)	6,000	2,000	28,000	DIST

Similarly, sea time can be determined by:

$$\text{STIME} = (\text{NSHIP} \times \text{FREQ}) - \text{PTIME}$$

where STIME = sea time per round-trip voyage in days
 NSHIP = the number of ships required to provide the given service.

Thus, by knowing the ship's speed and the sea time, we can determine the maximum voyage length for which a given number of ships can provide the specified service:

$$\text{MVL} = \text{STIME} \times \text{VK} \times 24 \frac{\text{hour}}{\text{day}}$$

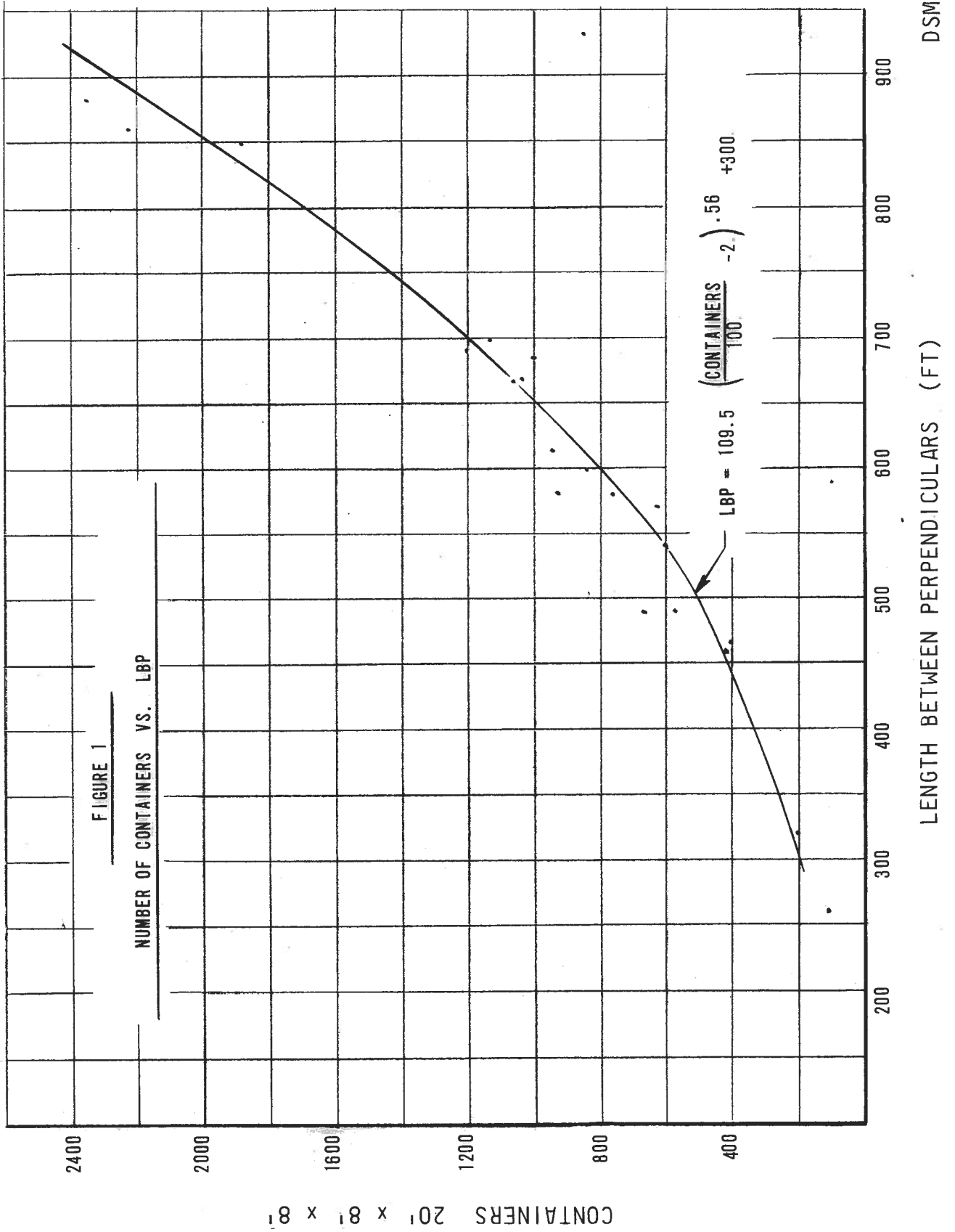
where MVL = maximum voyage length in nautical miles.
 By comparing the maximum voyage length at each increment in the number of ships with the desired voyage length (DIST), the number of ships needed to provide the specified service can be calculated.

Once the basic quantities (ship speed, containers per ship, number of ships required) have been established, the dimensions and costs of the required ships can be estimated. This will, at several points, necessitate "cut and try" iteration techniques. However, until better methods are made available, they must be tolerated.

A first estimate of the length of the required container ship can be obtained from the data in Figure 1. The dashed line shown was empirically derived, and is equivalent to:

$$\text{LBP} = 109.5 \left(\frac{\text{CAP}}{100} - 2 \right)^{.56} + 300$$

where LBP = length between perpendiculars, in feet.
 This relationship is necessarily crude, and a ship size determined in this manner must be refined, but it serves as a useful first stab.



The remaining dimensions of the proposed ship can now be estimated. Figure 2 shows a plot of beam, depth, and draft versus length for current ships, and serves as the basis for the ships "designed" by the computer program. The equations for the relationships between beam, depth, draft, and LBP are as follows:

$$\text{BEAM (LBP} \leq 707 \text{ ft)} = .133 \times \text{LBP} + 8$$

$$\text{BEAM (LBP} > 707 \text{ ft)} = 102$$

$$\text{DEPTH} = .055 \times \text{LBP} + 17$$

$$\text{DRAFT} = .0067 \times \text{LBP} + 26$$

where all units are in feet. These relationships are based on specific knowledge of the ships involved. For such a limited number of data points, I feel that the use of any mathematical curve-definition method could be misleading. (This applies to the determination of all empirical equations which follow.)

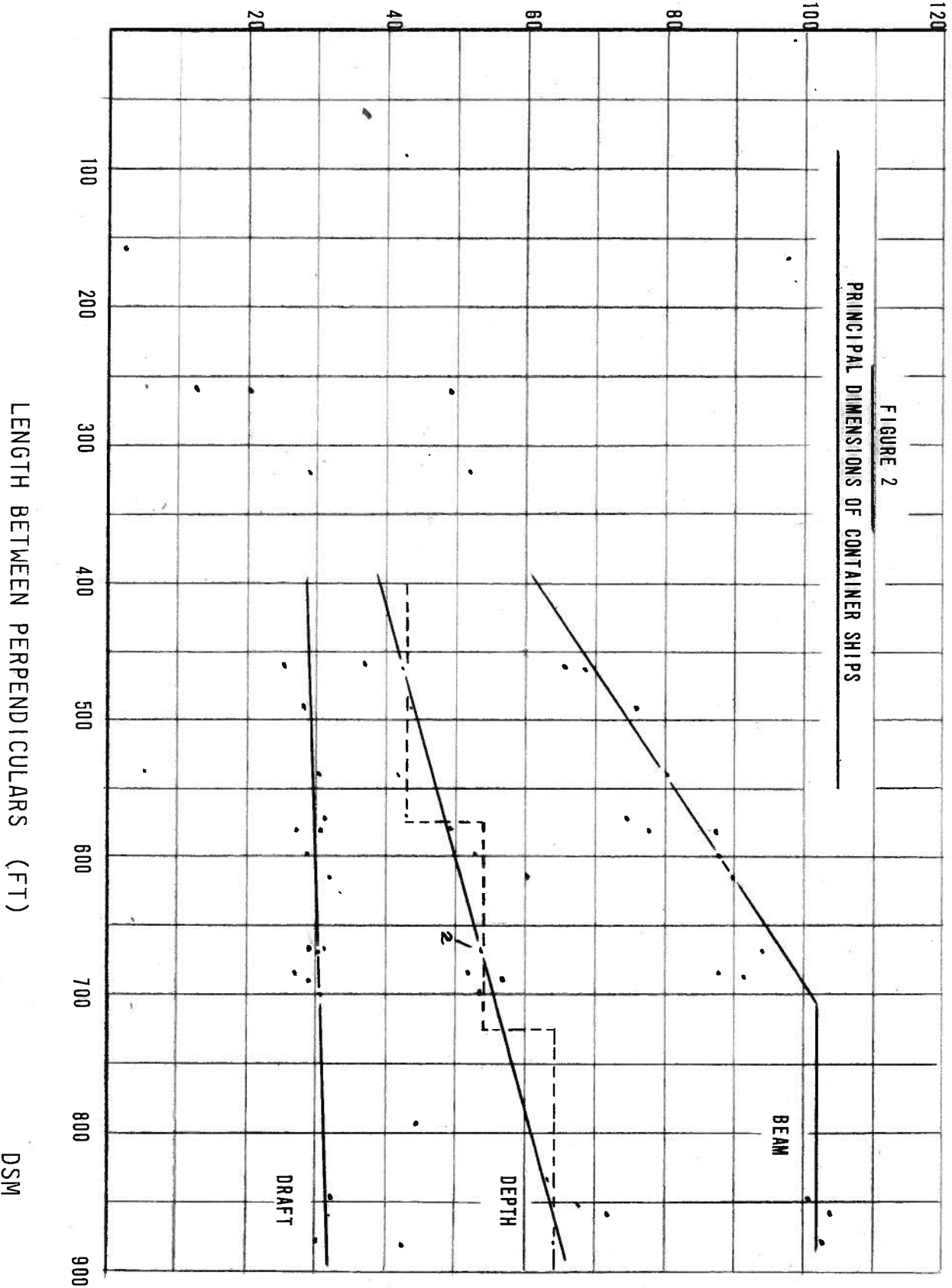
It could be argued that the depth relation should be a "step" function, because the depth will vary with the number of containers in the container stack. Such a function is shown as a dashed line on Figure 2. This approach was finally rejected for two reasons (perhaps one reason and one rationalization):

- (1) The use of any stairstep function would make the iterative procedures on which the computer depends considerably more difficult and time consuming.
- (2) The current variation in deck and hatch-coaming design tends to invalidate any strict "depth-container stack height" relationship.

In any event, the linear LBP-depth assumption yields acceptable results and can be tolerated.

BEAM, DEPTH, DRAFT (FT)

FIGURE 2
PRINCIPAL DIMENSIONS OF CONTAINER SHIPS



LENGTH BETWEEN PERPENDICULARS (FT)

DSM

The LBP-depth relationship may require changes if marine underwriters' current complaints of excessive damage to containers stowed on deck are carried to their logical end. However, any resultant increase in depth requirements can easily be incorporated in the program.

Obtaining a more accurate estimate of a ship's container capacity is now possible. This is accomplished by considering independently the containers stowed below hatch, and those carried on deck.

Figure 3A shows the relationship between the quantity of containers below deck and the approximate internal volume of the ship. As indicated, the appropriate equations are:

$$CBEL = .61 (MCN)^2 + 24.4 (MCN) + 58$$

$$MCN = LBP \times BEAM \times DEPTH \times CB / 100,000$$

where CBEL = containers below deck (hatch) in
20-ft x 8-ft x 8-ft vans

MCN = modified cubic number (ft³)

CB = block coefficient

From these equations, it is apparent that a ship's container capacity varies significantly with changes in the block coefficient. The relationship is not direct, however, because the number of containers carried above deck is largely independent of the block coefficient.

Determination of the number of containers carried on deck is somewhat more complex. Since container ships are stability-critical, the deck capacity of a given ship varies with the assumed weight per container. In practice, this weight ranges from 10 to 18 long tons per 20-ft x 8-ft x 8-ft van.* Thus, it is necessary to consider the weight of containers carried above deck, rather than the number.

*Large (35- and 40-ft) containers generally have higher assumed cargo stowage factors than 20-ft vans. Hence, when the larger containers are reduced volumetrically to a 20-ft x 8-ft x 8-ft base, this large variation in container weights results.

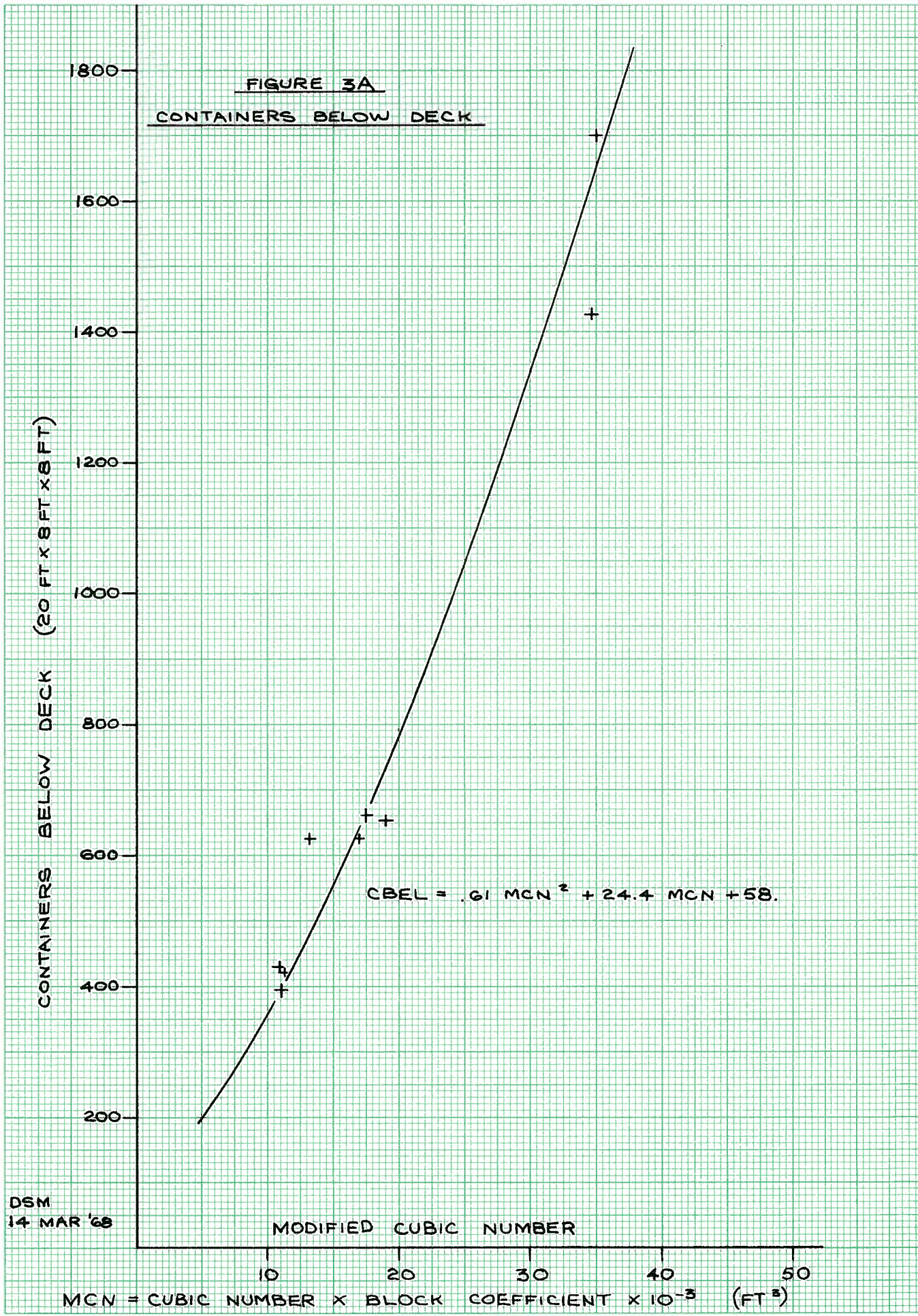


Figure 3B, then, shows the above-deck container weight plotted against a function of available deck area. Other, more sophisticated, approaches were explored, but none proved as satisfactory as the following:

$$WABV = 791 \times (DKAR) + 160$$

$$DKAR = LBP \times BEAM \times 10^{-4}$$

where WABV = weight of containers carried above deck
 (long tons)
 DKAR = a function of deck area (ft²).

The container weight calculated above assumes that no container cranes are carried aboard ship, and that the containers are secured with standard lashing cables. If ship-board cranes are anticipated, WABV should be reduced by approximately 150 long tons per crane. Similarly, reduce WABV by 6.5 percent if a rigid securing system of buttresses and frames is planned. These reductions must then be added to the weight of outfit and hull engineering.

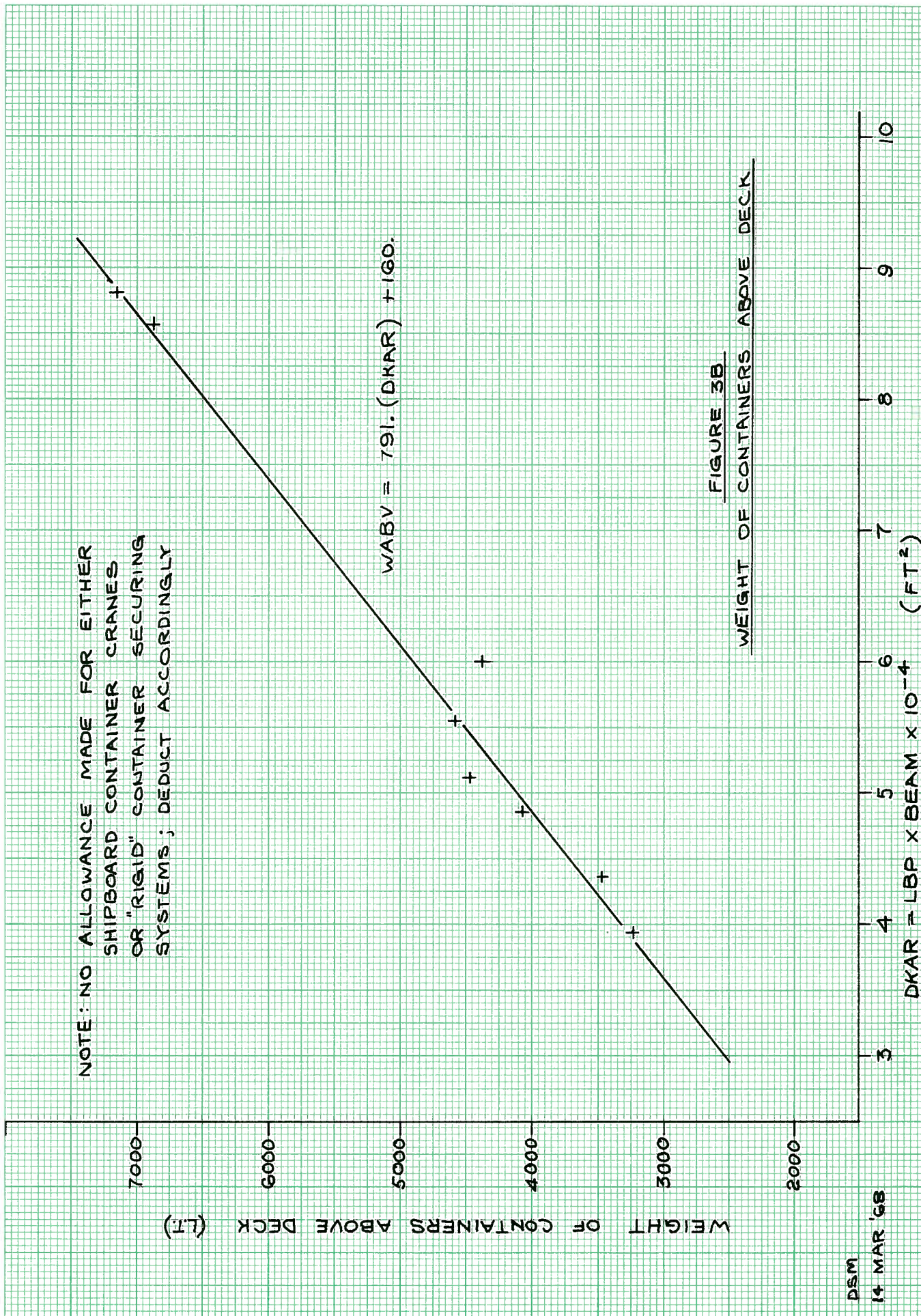
Finally, the number of containers which may safely be carried on deck can be estimated:

$$CABV = WABV / CDEN$$

where CABV = containers above deck (20-ft x 8-ft x 8-ft
 containers)
 CDEN = container density (long tons per 20-ft x 8-ft
 x 8-ft van).

Note that, while this method provides a reasonable estimate, more exact determination of above-deck container capacity would require insertion of a stability subroutine into the program. This can readily be done, if it is deemed worthwhile.

The total container capacity of the ship being investigated is thus:



111 19

$$CAP = CABV + CBEL$$

where CAP = total container capacity (20-ft x 8-ft x 8-ft containers).

The actual container capacity can now be compared with the desired capacity (CONT, previously calculated), and adjustments made as required. As presently written, the algorithm's iterative procedure to increase container capacity is as follows:

- (1) Increase the block coefficient in increments of .01 from an initial value of .57 to a maximum of .63.
- (2) Whenever the block coefficient reaches .63 and container capacity is still inadequate, reset the block coefficient at .57 and increase the ship's length by 1.5 percent. Then repeat step 1.

After each increment, the actual and desired container capacities are compared; adequate agreement will terminate the process. Reductions in capacity, when necessary, are handled in a similar manner. In either event, eventually a vessel with the required container capacity and a block coefficient between .57 and .63 will emerge.

A block coefficient between .57 and .63 was used because most unballasted container ships should fall within this range. This is because of weight considerations: an unballasted container ship's substantial beam requires a relatively fine hull form to bring the displacement in line with weights. While it is possible that the restriction of the block coefficient may, in specific situations, result in suboptimized ships, no serious skew is expected to result.

Once a ship's principal dimensions and block coefficient have been defined, it is possible to estimate horsepower, weights,

and building costs. However, because horsepower, displacement, and weights are interdependent, an iterative procedure must again be applied. Hence, the program performs the following:

- (1) Calculate displacement
- (2) Estimate shaft horsepower
- (3) Calculate and sum weights
- (4) Compare total weight and displacement
- (5) If displacement and total weight agree, terminate iteration. Otherwise, adjust either draft or LBP, and repeat process.

Changes less than 6 percent can be made by altering the draft. However, larger changes are made by increasing the LBP. This prevents excessive alteration of the draft, and insures that the ship's dimensions conform with those specified in Figure 2.

The iteration to insure that the total weight equals the displacement has several advantages. First, it insures that the cost estimates the computer supplies are based on "plausible" ships. If all weights check, then the ship is one that could conceivably be built. Second, the iterative technique recognizes the fuel requirements for differing voyage lengths, and clearly reflects the resultant changes in steel, machinery, and operating costs.

Perhaps the most important variable in ship cost studies is the horsepower estimate. Crew costs, fuel costs, insurance expenditures, and building costs all relate directly to the original horsepower assumed. For this reason, considerable effort should be expended insuring that horsepower values used are reasonable.

The effective horsepower values used in the program were based on the Taylor Standard Series (4). An external function used Taylor's residual resistance profiles to return an effective horsepower estimate to the main program for each

ship considered. Since effective horsepower is a function of displacement, the Taylor subroutine was inserted into the iterative weight and displacement loop.

The main advantage of using the Taylor Standard Series was that a systematic variation of effective horsepower was achieved. On the other hand, one major problem was encountered: Because container ships have high volumetric coefficients,* they, at times, lie in regions in which the residual resistance coefficient is not defined by the Taylor Series. This is particularly true in the high speed-length ratio ranges ($V/\sqrt{L} > 1.0$). Hence, in such cases, the program is unable to provide cost estimates, and alternative horsepower-estimation methods must be substituted.

A second objection to using the Taylor Standard Series is that it can in no way account for the effect of bulbous bows, or other such innovations. However, in spite of these drawbacks, it provides better relative horsepower estimation than any of a number of "quick and dirty" formulae.

Once effective horsepower is determined, the problem of converting it into shaft horsepower is formidable. Two factors help simplify the problem, however:

- (1) Because the block coefficient of container ships is varied only between .57 and .63, the flow of water into the propeller is, for a given assumed hull form, roughly uniform for all ships considered.
- (2) Because the draft is almost independent of ship length, the maximum propeller diameter allowable is almost constant for either twin- or single-screw options.

However, even with these assumptions, the path is rocky. Attempts at synthesizing propulsive coefficients by considering

*submerged volume / (LBP)³

component efficiencies proved futile. Hence, I suggest the following as being acceptable:

for $EHP \leq 20,000$

$$PCOEF = .73 - .09 \left(\frac{EHP}{20,000} \right)$$

for $EHP > 20,000$

$$PCOEF = .68 - .09 \left(\frac{EHP - 20,000}{20,000} \right)$$

where EHP = effective horsepower
 $PCOEF$ = propulsive coefficient.

This assumes that the maximum shaft horsepower that can be reasonably handled on one shaft is approximately 32,000. The relationships described are shown in Figure 4.

One refinement is appended to take into account the effect of the water's speed of advance into the propeller. The propulsive coefficient is adjusted by the following:

$$PCOEF = PCOEF - \left[\left(\frac{17 - VK}{3} \right) \times .01 \right]$$

Note that the correction may be positive.

Finally, the shaft horsepower can be calculated. This is accomplished by adding a 25 percent service margin and a 3 percent margin for shaft losses. The 25 percent service margin is consistent with the earlier definition of "normal sea speed." Thus, we have:

$$SHP = \frac{EHP}{PCOEF} \times 1.25 \times 1.03$$

where SHP = shaft horsepower.

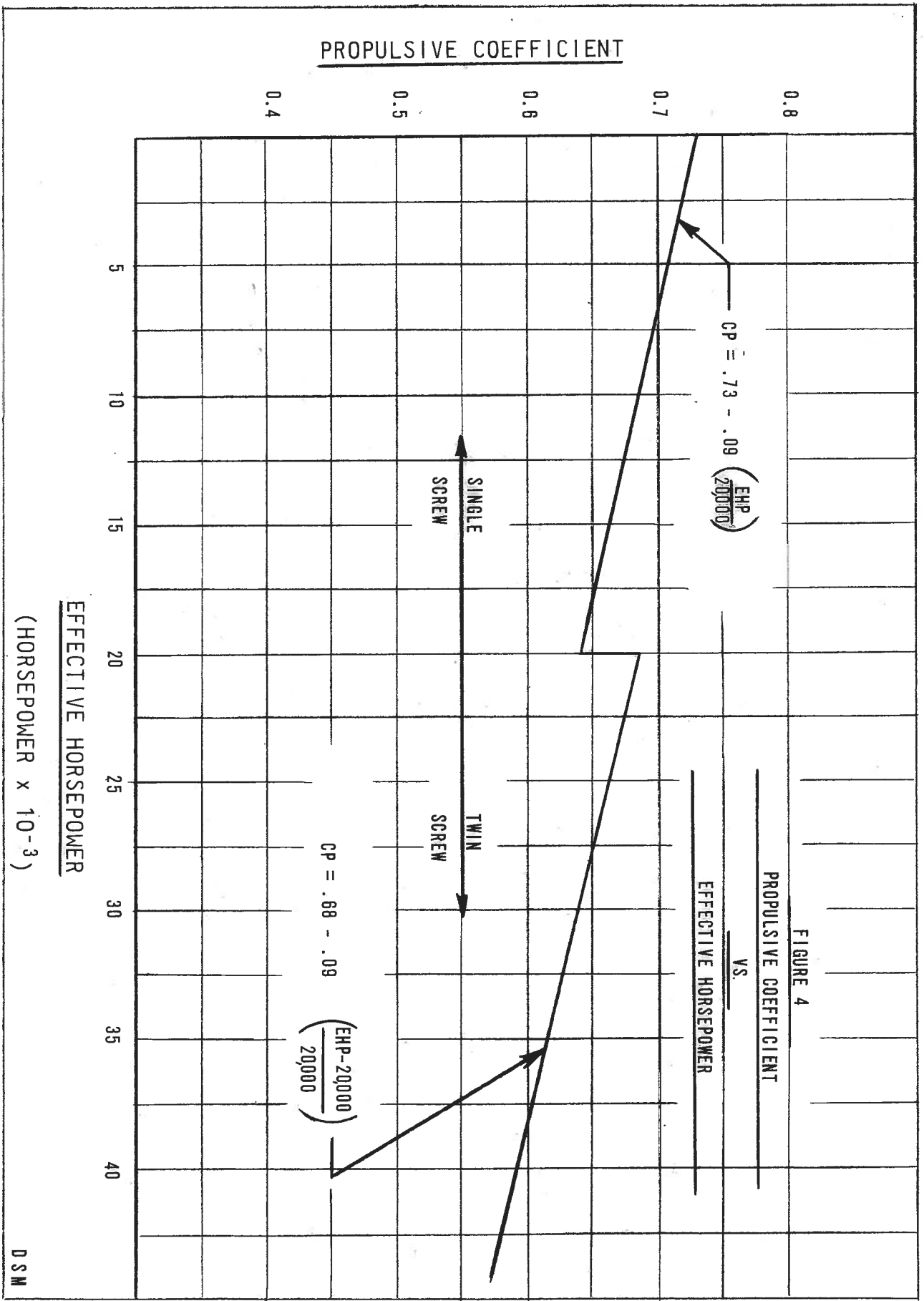


FIGURE 4
 PROPULSIVE COEFFICIENT
 VS.
 EFFECTIVE HORSEPOWER

EFFECTIVE HORSEPOWER
 (HORSEPOWER x 10⁻³)

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Weights

All of the weight estimates presented in this paper are based on the work of Benford (5, 6), with the specific relationships used being summarized in Table 2. Two categories require special comment, however, because they pertain specifically to container ships.

The steel hull weight of a container ship is very close to the equivalent weight for a conventional cargo ship. Savings in lower decks that are eliminated or largely removed compensate for the weight of additional longitudinal bulkheads and heavier deck plating on the strength deck. This is verified by empirical data.

However, outfitting weights are much lower in container ships than break-bulk ships. Empirical evidence indicates that the weight of outfit and hull engineering can be estimated by:

$$WOHE = -.71 \left(\frac{CN}{1000}\right)^2 + 93.5 \left(\frac{CN}{1000}\right) - 104$$

The relationship is plotted in Figure 5.* Note that the weight of neither shipboard container cranes nor rigid securing systems for above-deck containers is included.

Costs

Once all weights have been estimated, it is possible to outline building costs. The specific relationships used are based on the work of Benford (6) and Krappinger (7). All costs are for subsidized construction in the United States; unsubsidized ships will cost 10 to 20 percent less. An hourly wage rate

*Plots of other weight categories may be found in (5, 7).

Table 2
Weights--Long Tons

Item	Relationship
Steel hull	$WS = .340 \times \left(\frac{CN}{1000}\right)^{.9} \times ONE \times THREE$ <p>where:</p> $ONE = .675 + \left(\frac{CB}{2}\right)$ $THREE = .00585 \left(\frac{LBP}{DEPTH} - 8.3\right)^{1.8} + .939$
Outfit and hull engineering	$WOHE = -.71 \left(\frac{CN}{1000}\right)^2 + 93.5 \left(\frac{CN}{1000}\right) - 104 \quad (1)$
Machinery (single screw)	$WMACH = 214 \times \left(\frac{SHP}{1000}\right)^{.5}$
Machinery (twin screw)	$WMACH = 1.15 \times (WMACH) \text{ single screw}$
Fuel	$WFUEL = (STIME / 2) \times 1.3 [10 + (5.18 \times \frac{SHP}{1000})] \quad (2)$
Potable water	$WPWTR = 40 \times 2 \times STIME \times .167 \quad (3)$
Feed water	$FWWTR = .887 \times (STIME / 2) \times \left(\frac{SHP}{1000}\right) \times 1.5 \quad (4)$
Crew, stores, etc.	$WCRST = 30$
Containers	$WCONT = 14.5 \times CAP$

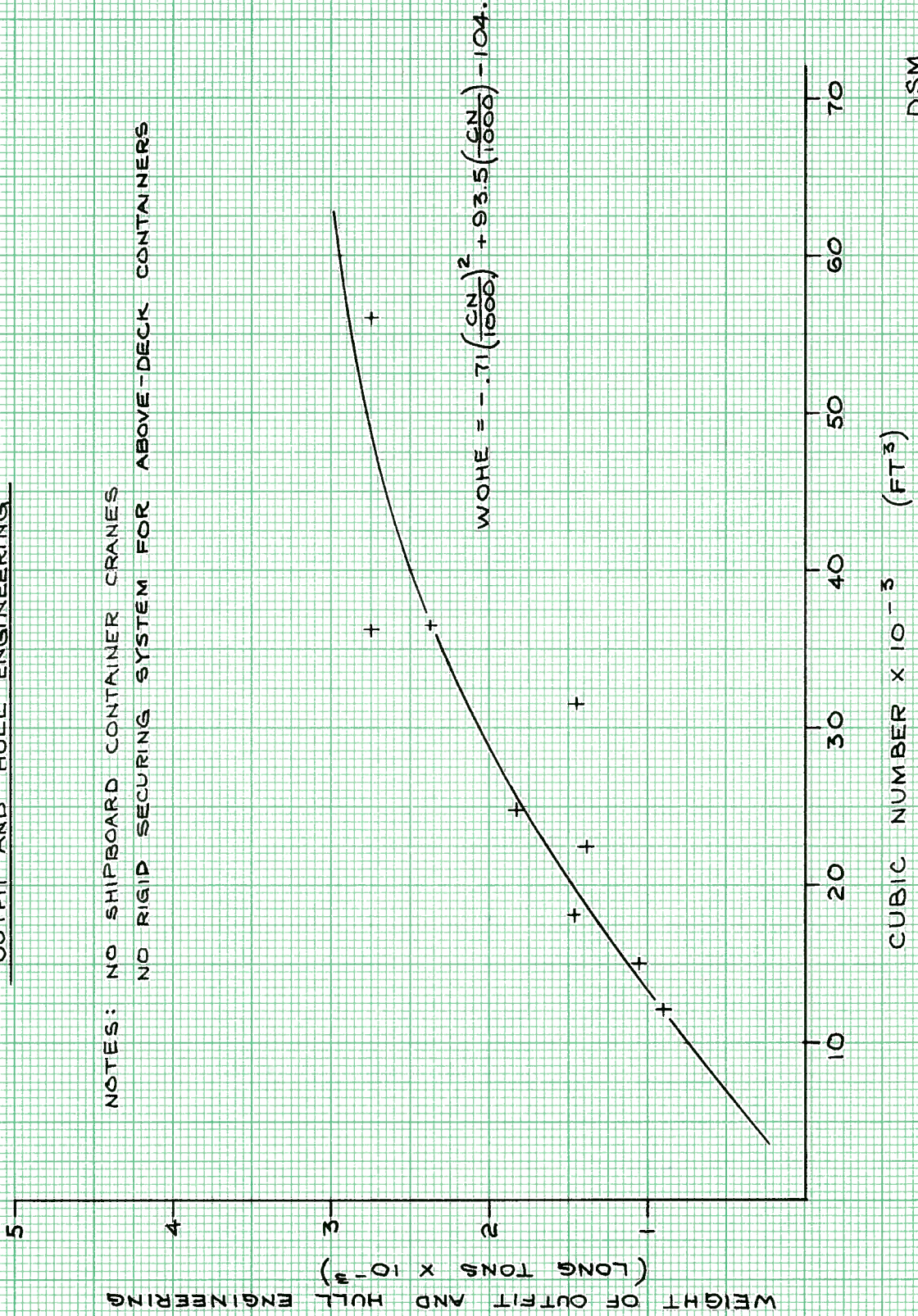
Table 2
continued

All consumables based on one-way voyage length.

- (1) Assumes no shipboard container cranes, no rigid securing system for above-deck containers
- (2) Assumes 30 percent margin for refrigeration and contingencies
- (3) Assumes a crew of 40 men, no evaporators, and a 100 percent margin for contingencies
- (4) Assumes no evaporators and a 50 percent margin for contingencies

FIGURE 5
OUTFIT AND HULL ENGINEERING

NOTES: NO SHIPBOARD CONTAINER CRANES
NO RIGID SECURING SYSTEM FOR ABOVE-DECK CONTAINERS



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6x01

of \$3.30 is used to estimate labor costs. Table 3 summarizes all building cost formulae.

Because it is probable that, if more than one vessel is required, all ships in a fleet of new container ships would be built in a single shipyard, it is appropriate to assign savings due to multiple ship construction. Hence, the total shipyard bill for the container ship fleet would be:

$$CFLT = \left(\frac{CONE}{NSHIP \cdot .097} \right) \times NSHIP$$

Finally, owner's costs can be tallied, and a final fleet cost determined. Owner's costs can be estimated as:

$$COWN = CONE \times [.03 + (.0175 \times NSHIP)]$$

The total fleet cost is then:

$$TCFLT = CFLT + COWN$$

For system profitability studies, only the initial investment for each alternative is required. Hence, no further computations are needed. However, if a minimum-cost analysis is being applied to a subsystem, then the total fleet cost must be reduced to an annual allowance for capital recovery.

As presently written, the algorithm makes three assumptions, and computes an annual depreciation allowance. The four pertinent assumptions are:

- (1) An overall container system level of profitability of 10 percent, after tax
- (2) Straight-line depreciation, zero scrap value
- (3) An economic life span of 20 years
- (4) A tax rate of 48 percent.

Converting the after-tax interest rate to the appropriate

Table 3
Building Costs--Dollars

Item	Relationship
Hull structure materials labor	$\text{CSTL} = 227 \times \text{WS}$ $\text{CLST} = 3.3 \times 90,000 \times \left(\frac{\text{WS}}{1000}\right)^{.85}$
Outfit and hull engineering	
materials labor-outfit	$\text{COHE} = 1800 \times \text{WOHE}$ $\text{CLO} = 3.3 \times 20,000 \times \left(\frac{\text{WOHE}}{200}\right)^{.9}$
labor-hull engineering	$\text{CLHE} = 3.3 \times 51,000 \times \left(\frac{\text{WOHE}}{200}\right)^{.75}$
Machinery ¹	
<u>single screw</u> materials	$\text{CM} = 585,000 \times \left(\frac{\text{SHP}}{1000}\right)^{.5}$
labor	$\text{CLM} = 3.3 \times 27,900 \times \left(\frac{\text{SHP}}{1000}\right)^{.5}$
<u>twin screw</u> materials labor	$\text{CM} = 1.15 \text{ (CM) single screw}$ $\text{CLM} = 1.15 \text{ (CLM) single screw}$
Total cost of materials ²	$\text{TCMAT} = 1.15 \times (\text{CSTL} + \text{COHE} + \text{CM})$

Table 3
continued

Item	Relationship
Total labor cost ³	$TCLAB = 1.3 \times (CLST + CLO + CLHE + CLM)$
Overhead ⁴	$OHVD = .7 \times TCLAB$
Cost of one vessel	$CONE = 1.05 \times (TCMAT + TCLAB + OHVD)$

1. Machinery costs assume no extensive automation
2. Assumes a 15 percent margin for wastage
3. Assumes a 30 percent margin for miscellaneous labor
4. Overhead taken as 70 percent of total labor costs
5. Assumes a 5 percent margin for profit

before-tax rate of return, and applying the capital recovery factor:

$$\text{ANCRC} = .1795 \times \text{TCFLT}$$

where ANCRC = the annual cost of capital recovery.

Note, however, that the preceding must be altered to conform with any of the following factors that may apply:

- (1) Before-tax system rates of return varying from 10 percent
- (2) Construction subsidies
- (3) Alternative depreciation schemes
- (4) Tax credits.

An estimate of the annual direct operating costs of the container ship subsystem is required for both system level of profitability and subsystem minimum-cost analyses. In the profitability case, operating expenses must be deducted from the system's annual revenue to determine an annual before-tax return for the system. However, for a minimum-cost analysis, direct operating costs must be added to annual capital recovery costs to compute the total annual expense each alternative involves.

Annual operating costs are, once again, based on Benford (6). However, some changes have been made to adapt his relationships to container ships. The relationships used are summarized in Table 4. Costs are for US flag vessels with no significant degree of automation.

Once the computer has estimated all operating costs, it sums the individual costs into the annual operating expense per ship (COPER), then multiplies by the number of ships to determine the annual fleet cost of operation (FCOP). Finally,

Table 4
Operating Costs--Dollars 1967

Item	Relationship
Crew size	$\text{NCREW} = 1.25 \left(13 \times \left(\frac{\text{CN}}{1000} \right)^{.67} \right. \\ \left. + \text{CENG} \times \left(\frac{\text{SHP}}{1000} \right)^{.2} \right)$ <p>where:</p> $\text{CENG} = 12 \text{ SHP} \leq 30,000$ $\text{CENG} = 15 \text{ SHP} > 30,000$
Crew cost	$\text{CCREW} = \$16,250 \times \text{NCREW}$
Subsistence	$\text{STNCE} = \$800 \times \text{NCREW}$
Maintenance and repair	$\text{CMR} = \$9,000 \times \left(\frac{\text{CN}}{1000} \right)^{.67} \\ + \$4,500 \times \left(\frac{\text{SHP}}{1000} \right)^{.67}$
Stores and supplies	$\text{NCREW} \leq 50$ $\text{CSTOR} = \$80 \times \left(\frac{\text{NCREW}}{10} \right)^4$
	$\text{NCREW} > 50$ $\text{CSTOR} = \$50,000 + \$4,000 (\text{NCREW} - 50)$
War risk insurance	$\text{WRINS} = .001 \times (\text{TCFLT} / \text{NSHIP})$
Protection and indemnity insurance	$\text{PINS} = 965 \times \text{NCREW}$
Hull and machinery insurance	$\text{HMINS} = 10,000 + .007 (\text{TCFLT} / \text{NSHIP})$
Overhead	$\text{COHV} = 65,000 + 2 \times \text{CN}$

the total annual cost of the container ship subsystem is calculated:

$$\text{TCOST} = \text{FCOP} + \text{ANCRC}$$

All costs relevant to the operation of the container ships have now been determined.

The program, as it is printed in the Appendix, has numerous constraints and prints out an appropriate index number when any limitation is exceeded. These limitations, and the index value relating to each, are listed in Table 5.

Table 5
Program Constraints

Index	Constraint
1	Residual resistance coefficients are not defined by the Taylor Standard Series for this ship at this speed.
2	Ship size, based on required container capacity, is greater than the maximum calculated by the program.
3	Ship size, based on required container capacity, is less than the minimum calculated by the program.
4	The limits of Taylor Standard Series program are exceeded.
5	The horsepower required by this ship is greater than that which can be reasonably handled in a twin-screw ship.

PART III

TYPICAL RESULTS AND DISCUSSION

Typical Results and Discussion

Like all computer techniques, the algorithm developed in Part II is a double-edged sword. When used judiciously, it can provide meaningful input data for the rational development of a container system. However, when used indiscriminately, it simply generates reams of data which are understood by few and trusted by none. Hence, this section will present typical output, and discuss its relevance to the optimization procedures outlined earlier.

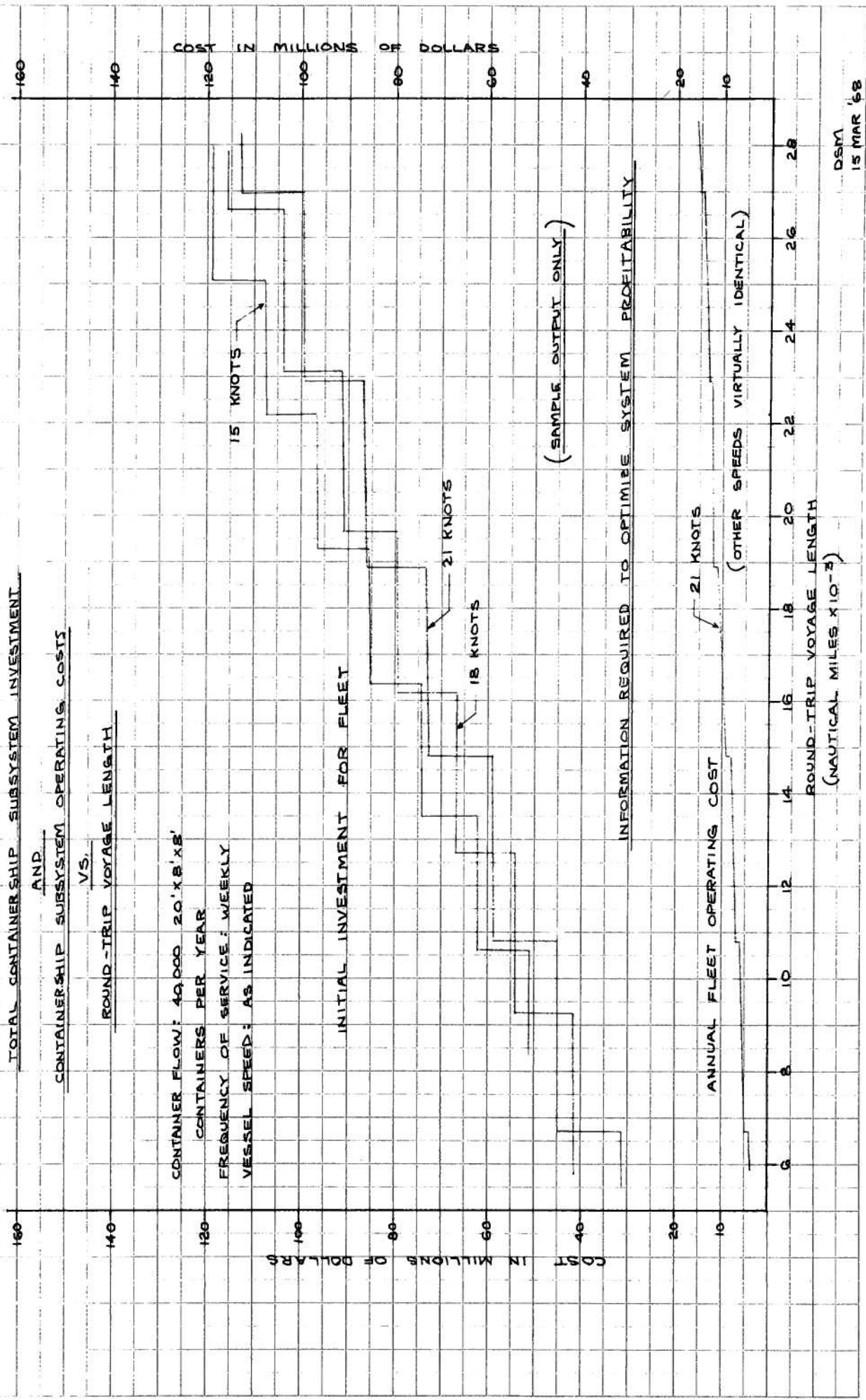
As mentioned in Part I, optimizing the profitability level of a system requires the following data for each subsystem:

- (1) Initial subsystem investment cost
- (2) Direct operating costs of the subsystem.

For the container ship subsystem, this data can conveniently be represented in graphs such as Figure 6. For clarity and brevity, this plot shows only three vessel speeds and one container flow rate. However, if it were expanded by the addition of more speed curves and container flow curve groups, and if a similar chart were prepared for alternative service frequencies, it would be possible, through interpolation, to estimate investment and operating costs for virtually any proposed container service.

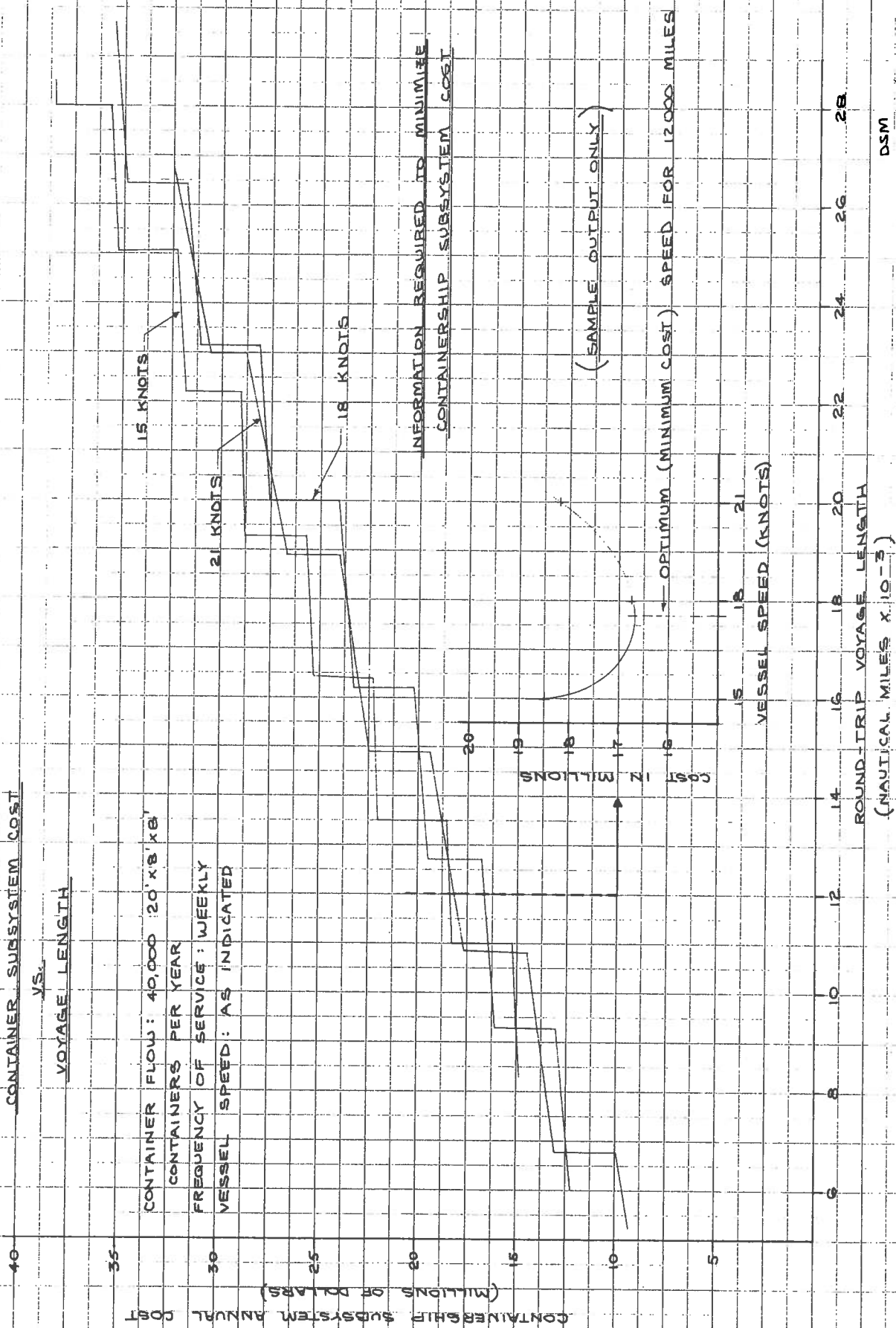
Similarly, if the container system is to be optimized by minimizing subsystem costs, relevant container ship data can be summarized as in Figure 7. Instead of indicating investment and operating costs, the total annual cost of providing a given service is specified. As stipulated in Part I, this total cost must include both direct operating costs and the annual

FIGURE 6
TOTAL CONTAINER SHIP SUBSYSTEM INVESTMENT
AND
CONTAINER SHIP SUBSYSTEM OPERATING COSTS
VS.
ROUND-TRIP VOYAGE LENGTH



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FIGURE 7
CONTAINER SUBSYSTEM COST
VS.
VOYAGE LENGTH



cost of capital recovery. Once again, the plots can be expanded to cover a variety of possible situations.

Note that these methods of data presentation may be revised to suit any given situation. If one specific trade route is to be investigated, the round-trip voyage length may be fixed, and costs plotted against container flow. Frequency of service may also be used as the variable. The only criterion for presenting the data is that it clearly display the effects on costs of changes in one or more of the following:

- (1) Container flow rate
- (2) Frequency of service
- (3) Ship speed
- (4) Voyage length.

Only when planners are aware of the costs involved in, say, increasing ship speed 2 knots to gain a competitive edge, can rational decisions evolve.

Finally, several comments should be directed at the algorithm's flexibility. While it is intended primarily to estimate building and operating costs, it could easily be adapted to carry out special studies. One such study might be to determine whether or not bulk liquid cargo should be carried in addition to containers. Further, costs may be reduced to a "per day" or "per container space" base. Also, with the addition of a stability subroutine, container ships carrying permanent ballast could be investigated. Numerous sensitivity studies can be undertaken. In short, the algorithm as presented is a "lump of clay" which may be molded into any desired shape.

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Appendix
The Program

\$COMPILE MAD, PRINT OBJECT, PUNCH OBJECT

MAD (17 MAY 1967 VERSION) PROGRAM LISTINGAPPENDIX

```

      INTEGER V,W,Y,Z,U,K,INDEX
      VECTOR VALUES AA=$ 1HO, 4HFREQ, S2, 4HQUAN, S2,
2     3HSPD, S2, 4HDIST, S2, 5HNSHIP, S3, 3HMVL, S3,
3     4HCONT, S2, 3HLBP, S3, 2HCB, S3, 3HLSW, S5, 4HCONE,
4     S6, 5HTCFLT, S6, 5HCOPER, S5, 5HTCOST, S5, 3HSHP,*$
      VECTOR VALUES BB=$1HO, S1, I2, S4, I2, S4, I2, S3, I2,
2     S4, F5.0, S2, F4.0, S2, F3.0, S2, F5.0, S2, E8.3,
3     S2, E9.3, S2, E8.3, S2, E9.3, S2, F6.0,*$
      VECTOR VALUES CC=$1HO, S1, I2, S4, I2, S4, I2, S4, I2,
2     S4, I2*$
      EXECUTE REDAT.
      PRINT FORMAT AA
      CDEN=16.
      K=0
      THROUGH ALPHA, FOR Z = 7, 7, Z .G. 21
      THROUGH ALPHA, FOR Y = 10, 10, Y .G. 40
      THROUGH ALPHA, FOR W = 27, -3, W .L. 12
      THROUGH ALPHA, FOR V = 6, 2, V .G. 28
      FREQ=Z
      DIST=1000.*V
      QUAN=1000.*Y
      VK=W*1.
      WHENEVER FREQ .E. 7
      SAIL=51.
      OTHERWISE
      SAIL=(364./FREQ)-1.
      END OF CONDITIONAL
      CONT=QUAN/SAIL
      WHENEVER CONT .G. 2500.
      INDEX=2
      TRANSFER TO GNU
      OR WHENEVER CONT .L. 350.
      INDEX=3
      TRANSFER TO GNU
      END OF CONDITIONAL
      PTIME=2.* ((CONT/720.) + .25)
      THROUGH GAMMA, FOR U=1, 1, U.G.25
      NSHIP=U
      STIME=(NSHIP*FREQ)-PTIME
      MVL=STIME*VK*24.0
      GAMMA      WHENEVER MVL .GE. DIST, TRANSFER TO DELTA
      CB=.57
      DELTA     LBP=109.5* (((CONT/100.) -2.) .P. .56) + 300.
      RHO      WHENEVER LBP .G. 707.
      BEAM=102.

```

```

OTHERWISE
BEAM=(.133*LBP) + 8.
END OF CONDITIONAL
DEPTH=(.055*LBP) + 17.
CN=LBP*BEAM*DEPTH/100.
MCN=LBP*BEAM*DEPTH*CB/100000.
CBEL=.61*(MCN .P. 2.) + 24.4*MCN + 58.
DKAR=LBP*BEAM/10000.
WABV=791.*DKAR + 160.
CABV=WABV/CDEN
CAP=CBEL + CABV
TEMP=CAP/CONT
WHENEVER TEMP .L. .99
WHENEVER CB .L. .63
CB=CB + .01
OTHERWISE
CB=.57
LBP=1.015*LBP
END OF CONDITIONAL
TRANSFER TO RHO
OR WHENEVER TEMP .G. 1.02
LBP=.985*LBP
TRANSFER TO RHO
OTHERWISE
TRANSFER TO PI
END OF CONDITIONAL
PI DRAFT=26. + (.0067*LBP)
DCON=DRAFT
SPDLG=VK/(LBP .P. .5)
MU DISP=CB*LBP*BEAM*DRAFT/35.
ONE=0.675 + C.5*CB
THREE=.00585*((LBP/DEPTH)-8.3) .P. 1.8) + .939
WS=340.*((CN/1000.) .P. .9)*ONE*THREE
WOHE=-.71*((CN/1000.) .P. 2.) + 93.5*(CN/1000.)-104.
CP=CB/.985
EXECUTE TYLR.( LBP, BEAM, DRAFT, DISP, CP, SPDLG, EHP)
WHENEVER EHP .E. 1.0
INDEX=4
TRANSFER TO GNU
OR WHENEVER EHP .E. 2.0
INDEX=1
TRANSFER TO GNU
END OF CONDITIONAL
WHENEVER EHP .G. 80000.
INDEX=5
TRANSFER TO GNU
END OF CONDITIONAL
WHENEVER EHP .LE. 20000.
PCOEF= .73-(.09*(EHP/20000.))
OTHERWISE
PCOEF= .68 - (.09*((EHP-20000.)/20000.))
END OF CONDITIONAL

```

```

PCOEF=PCOEF- (((17.-VK ) /3.)* .01)
SHP=(EHP/PCOEF)*1.25*1.03
WMACH=214.*((SHP/1000.)*.P*.5)
WHENEVER EHP .G. 20000., WMACH=1.15*WMACH
LSW=WMACH+WOHE+WS
WFUEL=STIME*1.3*(10. +(5.18*(SHP/1000.)))*.5
WPWTR=40.* STIME * 2.*.167*.5
WFWTR=.887*STIME*(SHP/1000.)*1.5*.5
WCRST=30.
WCONT=CDEN*CAP
DWT=WCONT +WFUEL+ WPWTR + WFWTR+WCRST
WTOT=LSW+DWT
WHENEVER (DISP/WTOT) .L. 1.0
WHENEVER (DRAFT/DCON) .LE. 1.06
DRAFT=1.01*DRAFT
TRANSFER TO MU
OTHERWISE
LBP=1.01*LBP
TRANSFER TO MU
END OF CONDITIONAL
OR WHENEVER (DISP/WTOT) .G. 1.06
WHENEVER (DRAFT/DCON) .GE. .94
DRAFT=.99*DRAFT
TRANSFER TO MU
OTHERWISE
LBP=1.01 LBP
TRANSFER TO RHO
END OF CONDITIONAL
END OF CONDITIONAL
CSTL=227.*WS
CLST=90000.*((WS/1000.) .P. .85)*3.3
COHE=1800.*WOHE
CLO=3.3* 20000.*((WOHE/200.) .P. .9)
CLHE=3.3* 51000.* ((WOHE/200.) .P. .75)
CM=585000.*((SHP/1000.) .P. .5)
WHENEVER EHP .G. 20000., CM = 1.15 *CM
CLM=3.3* 29200.*((SHP/1000.) .P. .5)
WHENEVER EHP.G. 20000.,CLM=1.15*CLM
CMAT=CSTL +COHE +CM
CLAB=CLST +CLO +CLHE +CLM
TCMAT=1.15*CMAT
TCLAB=1.3*CLAB
OHVD=TCLAB*.7
CONE=(TCMAT + TCLAB + OHVD)*1.05
CFLT=(CONE/(NSHIP .P. .097))*NSHIP
COWN=CONE*(.03 + (.0175*NSHIP))
TCFLT=CFLT + COWN
CPS=TCFLT/NSHIP
ANCRC= .1795* TCFLT
WHENEVER EHP .LE. 20000.
CENG=12.
OTHERWISE
CENG=15.
END OF CONDITIONAL

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NCREW=1.25*(13.*((CN/1000.) .P. .167) + CENG*((SHIP/1000.)
1 .P. .2))
CCREW= 16250.*NCREW
STNCE=800.*NCREW
CMR=9000.*((CN/1000.) .P. .67) +4500.*((SHP/1000.) .P. .67
WHENEVER NCREW .LE. 50.
CSTOR= 80.* ((NCREW/10.) .P. 4.)
OTHERWISE
CSTOR=50000.+ 4000.* (NCREW-50.)
END OF CONDITIONAL
PINS= 965.*NCREW
HMINS= 10000.+ .007*(TCFLT/NSHIP)
COHV= 65000.+ 2.*CN
NPORT= 2.* SAIL/NSHIP
CPTV= NPORT*(250.+20. *(CN/1000.))
CPTD=(PTIME-1.0) *(SAIL/NSHIP) *(20.+10.*(CN/1000.))
SFUEL= STIME* (SAIL/NSHIP)*(63.+34.2*(SHP/1000.))
PFUEL=PTIME*(SAIL/NSHIP)*(DISP/1000.) *1.5
CFUEL= 2.2*(SFUEL+ PFUEL)
WRINS=.001*(TCFLT/NSHIP)
COPER=CCREW + STNCE + CMR + CSTOR + PINS + WRINS
1 + HMINS + COHV + CPTV + CPTD + CFUEL
FCOP=COPER*NSHIP
TCOST=FCOP+ANCRC
TRANSFER TO POI
GNU WHENEVER K .GE. 22
PRINT COMMENT $1$
PRINT FORMAT AA
K=0
END OF CONDITIONAL
K=K+1
PRINT FORMAT CC, Z, Y, W, V, INDEX
TRANSFER TO ALPHA
POI WHENEVER K .GE. 22
PRINT COMMENT $1$
PRINT FORMAT AA
K=0
END OF CONDITIONAL
K=K+1
PRINT FORMAT BB, Z, Y, W, V, U, MVL, CONT, LBP, CB,
2 LSW, CONE, TCFLT, COPER, TCOST, SHP
ALPHA CONTINUE
END OF PROGRAM

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FOLLOWING NAMES HAVE OCCURRED ONLY ONCE IN THIS PROGRAM.
Y WILL ALL BE ASSIGNED TO THE SAME LOCATION, AND
PILATION WILL CONTINUE.

CPS *122
TEMP *049

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