MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Naval Architecture and Marine Engineering

"OPTIMIZATION METHODS APPLIED TO CONTAINERSHIP DESIGN"

by

Chryssostomos Chryssostomidis
B.Sc. Durham University (King's College)
1965

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF
SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
January, 1967

Signature of Author ....
Department of Naval Architecture and Marine
Engineering, January 16, 1967

Certified by.... ....
Thesis Supervisor

Accepted by....... ....
Chairman, Departmental Committee on
Graduate Students

ABSTRACT

The new technique for optimizing multi-dimensional functions, developed in Refs. [1], [2], [3], [11], and [12] has been successfully applied in this report to the containership preliminary design problem. The containership design procedure is developed in detail and an attempt is made to justify each step of the procedure in Section II. The optimization criterion chosen is a least cost criterion and the necessity for including payload weight and payload volume error terms in the optimization criterion as was done in Ref. [3] is avoided in the current work. The optimization procedure developed for the containership also includes successful treatment of the discrete ship dimension problem which is engendered by the fact that containers are built in discrete sizes. Sample results obtained from the algorithm described in this report are shown in Table 9.

ACKNOWLEDGEMENTS

The author wishes to thank his supervisor, Professor Philip Mandel, for his continuous encouragement and advice during the course of this investigation and for his major revisions of the final draft, Mr. Reuven Leopold and Mr. David B. Mandel for their assistance at the beginning of this work, Miss Carol Cook for her assistance in the preparation of the manuscript and all his colleagues who have contributed their suggestions and criticisms.

The research reported in this thesis was carried out under the sponsorship of the United Aircraft Research Laboratories, East Hartford, Connecticut under M.I.T. DSR No. 70209. The author is grateful to United Aircraft for their interest in this subject and for their financial support.

All computations were performed at the Computation Center of the Massachusetts Institute of Technology.

CONTENTS

Chapter

CONTENTS
(cont)

CONTENTS
(cont)

LIST OF TABLES

NOMENCLATURE

B = ship beam

c = optimization criterion, output of a set of random variables, X ($c = f(X, \bar{P}, \bar{D})$)

c^* = output of sampling cycle yielding best previous value of c, $c^* = f(X^*, \bar{P}, \bar{D})$

C_b = block coefficient

C_F = frictional resistance coefficient

CH = container height

CL = container length

C_m = midship section coefficient

C_p = prismatic coefficient

C_R = residual resistance coefficient

C_v, CV = volumetric coefficient

CW = container width

D = ship depth

D = also, the array listing the container distribution

$\bar{D}$ = a D array with specified values

DBH = double bottom height

E = distance between refueling ports

$(EHP)_{bh}$ = effective horsepower (bare hull)

F_a = available freeboard

F_r = required freeboard

$f(\ )$ = function of ( )

NOMENCLATURE
(cont)

GM = metacentric height

GM_a = actual metacentric height

GM_r = required metacentric height

i = any integer between 1 and n $1 \leqslant i \leqslant n$

k = sampling cycle counter

L = total number of sampling loops in a complete optimization procedure

L = also, ship waterline length

LBP = length between perpediculars

M = exponent of exponential transformation function

n = number of independent random variables x_i, i = 1...n (i.e. dimensions of vector X)

N = maximum number of containers to be carried per voyage

P = the array listing the owner's requirements, given in Table 2

$\bar{P}$ = a P array with specified values

r = a particular integer between 1 and n $(1 \leq r \leq n)$

SHP = required installed shaft horsepower

T = ship draft

V = ship speed made good between two ports

$(Vol)_{db}$ = available volume in double bottom for fuel usage

$(Vol)_{st}$ = volume of settler tanks

WEC = maximum weight of each container when fully loaded

NOMENCLATURE
(cont)

W_b = weight of permanent ballast

W_f = weight of fuel

W_m = weight of machinery

W_o = weight of outfit

W_s = weight of hull steel

W_p = weight of payload and associated equipment

W_x = weight of miscellaneous dead weight

X = a set of independent variables yielding c, $X = (x_1 \ldots x_i \ldots x_n)$, given in Table 1.

X^* = set of random variables yielding c^*, $X^* = (x_1^* \ldots x_i^* \ldots x_n^*)$.

x_i = components of X corresponding to Δ, C_p, $V/\sqrt{L}$, C_m

x_i^* = components of x^*

y = random number generated by algorithm $(-1 \leq y \leq +1)$

z = random number generator $(0 \leq z \leq +1)$

α = transverse inertia coefficient

Δ = ship displacement

∇ = ship volume

I. Introduction

The cost of handling cargo in some trades has been estimated to be as high as 60% of a ship's total operating expenses. New developments in ship cargo gear, terminal facilities and mechanical handling methods have increased efficiency somewhat, but more basic changes are necessary if appreciable reductions in operating expenses are to be achieved. Such basic changes involve the use of large shipping containers, barges or trailer bodies as integral cargo units to be carried aboard the transporting vehicle. When containers are carried aboard ship, substantial cargo hold cubic capacity is wasted; nevertheless, the cumulative reductions in stevedore labor, port layover time, packing costs and pilferage claims far more than offset this disadvantage.

A random search optimization technique, first discussed in Ref. [1] and [2] and applied in Ref. [3] to the preliminary design of ordinary cargo ships and in Ref. [12] to tankers is applied in this report to the design of a containership. Since the design procedure for a containership differs in many marked respects from that of an ordinary cargo ship or tanker, the bulk of this report, Section II, is devoted to structuring a design model applicable to containerships. However, changes were also necessary in the optimization criterion and in the optimization technique itself. These are discussed in Sections III and IV.

The difference in design procedure between a containership and an ordinary cargo ship arises from the fact that the payload of the latter is usually specified only in terms of its total weight and volume whereas the payload of the former is specified in terms of number, dimensions and weight of individual containers. Hence, it follows that the principal dimensions of a containership are functions of the number, the distribution and the size of the containers it is to carry. Because of this fact, ship beam B, and depth D, are not treated as random variables in this report, but rather they assume specific values depending on the number, the distribution and the dimensions of the containers. While ship length L, is treated as a random variable in this report, it can only assume values greater than a calculated minimum value which is also a function of the number, the dimensions and the distribution of the containers.

The independent design variables adopted for the containership studies of this report are given in Table 1. The optimization technique searches out values of these four variables that will result in a least cost ship (amortized building cost plus yearly fuel operating cost) that satisfies a given set of owner's requirements, see Table 2. It does this by computing the cost (as just defined) of thousands of sample designs, each corresponding to a set of values of the independent variables as determined by the exponential random search transformation (Equ. 55), until a near least-cost design is achieved.

Table 1

Independent Ship Design Variables, x_i

Item	Symbol	Units	Variable
1) Displacement	Δ	long tons	x_1
2) Prismatic Coefficient	C_p	non-dimen.	x_2
3) Speed-length Ratio	$V/\sqrt{L}$	$\frac{\text{kts.}}{(\text{feet})^{\frac{1}{2}}}$	x_3
4) Midship Coefficient	C_m	non-dimen.	x_4

Table 2

List of Owner's Requirements

(i) The average speed to be made good between two or more specified ports, V*.

(ii) The distance between refueling ports, E.

(iii) Maximum number of containers to be carried per voyage, N.

(iv) Maximum weight of each container when fully loaded, WEC.

(v) The dimensions of each container.

---

*Since speed is an owner specified item, the independent ship design variable, $V/\sqrt{L} = x_3$ is in effect equivalent to the ship length, L, being an independent variable, that is:

$$L = (V/x_3)^2 \qquad (1)$$

Although this study is not concerned with how the values of the requirements of Table 2 are determined by the owner, it is clear that the following items must be considered in the course of this determination:

(i) The highway or rail restrictions which exist in the countries in which the owner wishes to trade. These restrictions will effect the size and the weight of each container.

(ii) The stowage factor of the cargo within each container.

(iii) The number of loaded containers awaiting shipment that the containership is likely to find at each of its ports of call. This may be limited by the available staging area at the wharf or by the flow of containers into the port.

Restrictions on the values that the independent variables of Table 1 can assume in this study are imposed by stability, freeboard, strength and powering considerations. For example, one of the restrictions imposed by strength considerations is an upper limit on the ship length/depth ratio, while realistic design practice may be invoked to impose a lower limit. For the container ship this is taken as:

$$10.0 \leq L/D \leq 14.5 \tag{2}$$

Since depth is fixed for any given container distribution, Equ. (2) serves to impose an upper and lower limit on the values that the ship length can take.

Other restrictions imposed by strength considerations are discussed in Sections II-3-b and II-4.

Since all computations of propulsion power are made using the Taylor's Standard Series, it is necessary to adhere to the data restrictions of Ref. [4]. These are given in Table 3. The upper restriction on the value of $V/\sqrt{L}$ has been raised from a value of 1.00 in Ref. [3] to 1.20 in the current report. This has been achieved at the expense of a small sacrifice in C_v coverage compared to Ref. [3] which, however, is of little consequence as far as containerships are concerned.

Other restrictions on the values that the independent variables of Table 1 and ship beam and depth can assume are summarized in Table 6. In addition the user imposes restrictions on the values that the ship displacement (independent variable, x_1) may assume as follows:

$$(x_1)_{min} \leqq x_1 \leqq (x_1)_{max} \tag{10a}$$

$(x_1)_{min}$ is obviously always taken as larger than the payload weight (the product of N x WEC) and $(x_1)_{max}$ is selected with the upper restriction on the value that C_v may assume (Equ. 6) in mind.

There may also be restrictions on the values that the independent valiables can assume stemming from navigational considerations. In the design of the containerships discussed in this report, navigational limits were not considered to be restrictive.

Table 3

Restrictions on Variables Imposed by Ref. [4].

Item	Symbol	Variable	Restriction	
Beam/draft ratio	B/T	$\left(\frac{BV}{x_3}\right)^2 \frac{x_2x_4}{x_1}(35)^*$	$2.25 \leqq B/T \leqq 3.75$	(3)
Speed-length Ratio	$V/\sqrt{L}$	x_3	$0.50 \leqq x_3 \leqq 1.20$	(4)
Prismatic Coef.	C_p	x_2	$0.48 \leqq x_2 \leqq 0.70$	(5)
Volumetric Coef.	C_v	$\frac{35\ x_1}{(V/x_3)^6}^{**}$	$0.001 \leqq C_v \leqq 0.006$	(6)
Midship Coef.	C_m	x_4	$0.80 \leqq x_4 \leqq 1.00^{***}$	(7)

---

*From Archimedes Principle, Table 1 and Equ. (1), the ship draft, T is:

$$T = \frac{35x_1}{x_2x_4B\left(\frac{V}{x_3}\right)^2} \tag{8}$$

for ships in salt water. Hence, the B/T ratio is:

$$B/T = \left(\frac{BV}{x_3}\right)^2 \left(\frac{x_2x_4}{x_1}\right)(35) \tag{9}$$

**The volumetric coefficient, $C_v = \frac{\nabla}{L^3} = \frac{35\Delta}{L^3} = \frac{35x_1}{(V/x_3)^6}$ (10)

***This restriction is not imposed by Ref. [4] but rather by usual values of this coefficient used in all ship design work. It is included in this table for convenience. All models of Ref. [4] have a fixed C_m value of 0.925.

II. Container Ship Design

I.I. Design Principles

The design procedure of a containership, treated in this section, is outlined in approximately the order in which a designer would undertake a containership design from inception. Each subheading of this section begins with a general discussion of the topic of the subheading and concludes with the specific decision made with respect to that item in the current report.

a) Container Size

Under the sponsorship of the American Material Handling Society and the American Society of Mechanical Engineers, The American Standards Association (A.S.A.) adopted standards for container sizes in 1961 and for container strength and fittings in 1962. Table 4 gives the A.S.A. standard container dimensions, tolerances and maximum gross weight. In 1965 the International Organization for Standardization (I.S.O.) tentatively adopted the A.S.A. standards in all respects except that strength standards were based on stacking containers only four high instead of six high as permitted in the A.S.A. standards.

For any given ship, it is preferable to use a single container size rather than mixed sizes. In the present study, the 20' x 8' x 8' container size is used along with the A.S.A. standard permitting a six high arrangement. However, the algorithm developed in this report has the flexibility of handling any container size and distribution.

b) Container Handling

Although standard heavy-lift cargo booms have been adopted for

Table 4

A.S.A. Standard Container Dimensions And Weights

Length	Width	Height	Maximum Gross Weight
+0" 40' - 0" -3/8"	+0" 8' - 0" -3/16"	+0" 8' - 0" -3/16"	30 long tons
+0" 29' - 11.25" -3/8"	+0" 8' - 0" -3/16"	+0" 8' - 0" -3/16"	25 long tons
+0" 19' - 10.25" -1/4"	+0" 8' - 0" -3/16"	+0" 8' - 0" -3/16"	20 long tons
+0 9' - 9.75" -3/16"	+0 8' - 0" -3/16"	+0 8' - 0" -3/16"	10 long tons

handling containers, the use of heavy-duty traveling cranes has been found to be far superior because of their faster loading cycle. The two basic types of traveling cranes are 1) shore based and 2) shipboard cranes. The choice of which type to use is dependent on the following factors:

(i) The shore based crane is advantageous in trades employing a large number of ships calling at a restricted number of ports. The shipboard crane will be advantageous in cases where a few ships call at many ports.

(ii) In general, shore based cranes do not require as much maintainance and repair work as shipboard cranes, which are subjected to 1) salt air and water environment and 2) the effects of ship's motions. While major repair work and parts replacement are very difficult at sea, the shore crane can be readily repaired while the ship is at sea with no resulting delays in loading operations.

(iii) With the shore based crane, the crane operator views the container entry location obliquely and from a considerable distance. In this case, a larger transverse "target area" must be provided between container cells compared to that necessary if a shipboard crane is used. With the latter crane, the operator views the container entry location directly from above, and the target area may be smaller. In order to provide the increased target area needed with shore based cranes, the container cells must be further apart transversely, thus forcing more of the ship's cubic capacity to be wasted.

(iv) The stability of a ship with a shipboard crane is impaired compared to that of a similar ship employing a shore based crane.

(v) The cargo deadweight of a ship with a shipboard crane is less than that of an otherwise identical ship employing a shore based crane, because of the weight of the crane.

(vi) Both types of crane have approximately the same loading cycle time since the loss of time in loading containers due to the oblique view from the shore based crane is offset by the greater travel speed of the shore based crane.

All facts considered, the shore based crane is chosen for the designs to be developed in this report. If the shipboard crane is to be used, slight modifications have to be made in the existing version of the program to include 1) the weight of the crane, 2) its effect on ship's stability, 3) possible changes in the engine room length, machinery weight and fuel weight due to the necessity for an additional generator.

c) Container Hold Arrangement

The speed with which cargo can be stowed within the hold of a ship is among other things a function of the number of directions in which the cargo must be moved within the hold. In a conventional cargo ship, both horizontal and vertical cargo movement is necessary for loading. These two operations are so time consuming that the longitudinally continuous hatch design was developed for the ordinary cargo ship to make horizontal movement of the cargo unnecessary. With the typical containership, horizontal move- of the containers during loading is also unnecessary.

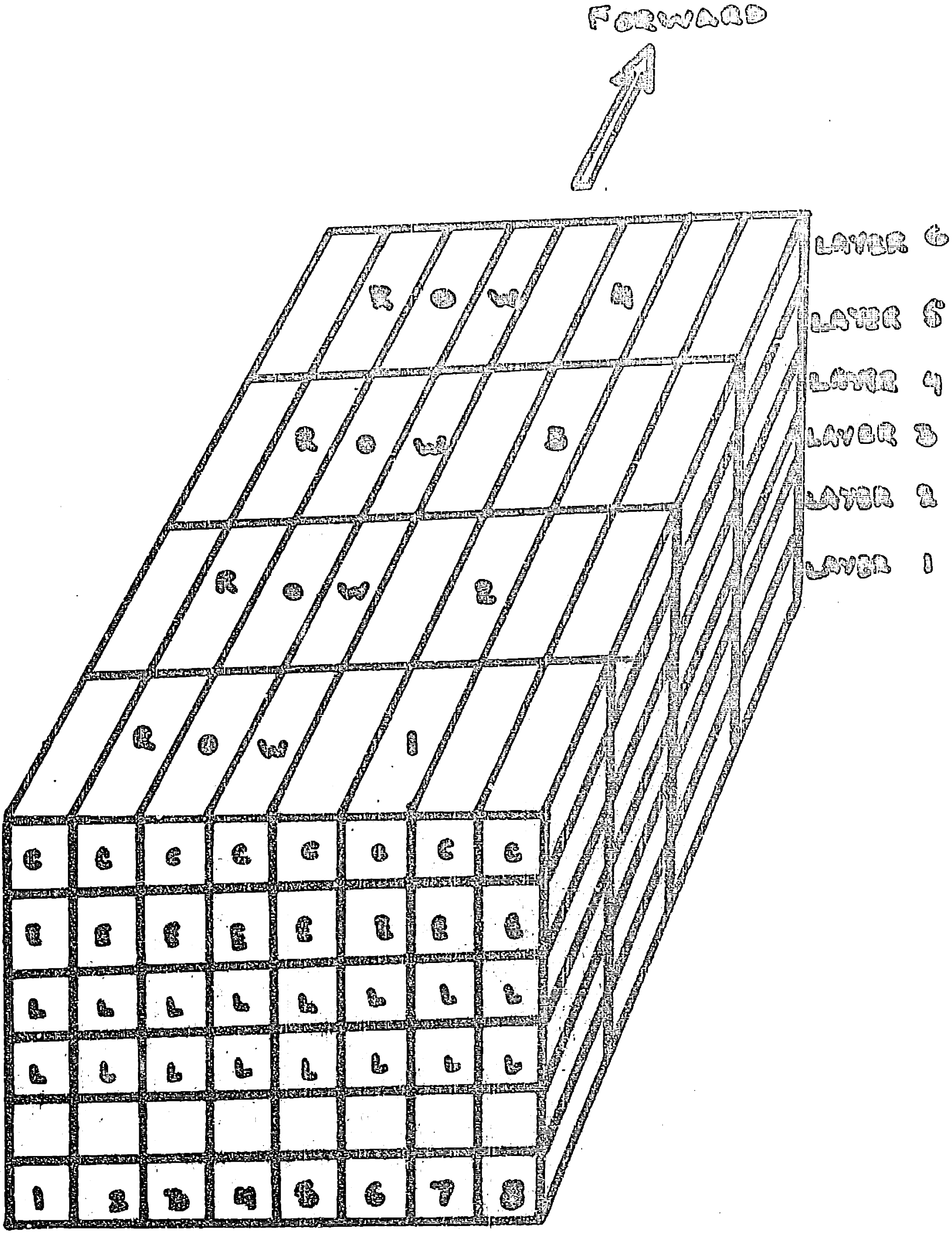
To accomplish loading with vertical motion only the containers are stacked, one on top of the other, six high in the hold, in accordance with the A.S.A. standard, with the corner posts of each container taking the load of the containers stacked above it. Each of these vertical columns is termed a cell. To assure proper line-up within each cell, the four corners of the cell are bounded by vertical angle guides running continuously from the top of the hatch coaming to the top of the inner bottom. These not only serve to guide the container vertically as it is loaded so that it lands squarely on the container beneath, but they also serve to prevent shifting of the containers at sea as the ship rolls and pitches.

Figure 1 defines the terms "cell", "row" and "layer" as used in this report and in standard containership terminology. A row is all cells aligned transversely between the two longitudinal bulkheads bounding the hold and consists of up to six layers of containers below the main deck.*

---

*The term "column" as used in the algorithm printout refers to a cell extended to include the containers above the main deck.

FIGURE 1. Definition Diagram for "Row", "Cell" and "Layer".



The guide angles used to line-up the containers in a cell are continuous steel angle sections varying in scantlings from 4" x 4" to 6" x 6" with a thickness of about 5/8". These scantlings are required to prevent distortion should the container become jammed in the cell owing to a heavy list during loading. To minimize the possibility of jamming, transverse clearances between guide angles and containers of about 1/2" and longitudinal clearances of about 3/4" are used.

At the top of each cell, a funnel-like arrangement is provided to facilitate entry of the container into the close fitting cell guide angles. When loading is done by shipboard crane, Ref. [5] recommends a net transverse clearance of about six inches between any two adjacent containers in their cells to provide adequate transverse target area, while if a shore based crane is used, nine inches are recommended.

The vertical load at the bottom corners of the lowest container in a cell is quite high, since the entire load is carried at the corners. For this reason, it is important to locate the container corners immediately over a longitudinal girder or solid floor, or preferably both. Also, doubler plates should be provided to prevent punching through the tank top and to provide an even stress distribution in the structure. For this study, the doubler plate thickness is taken as one inch.

The number of container rows per hold is limited by floodable length considerations. For a container ship with wing tanks and double bottom, this restricts the maximum length for a typical hold to about 100 feet, which, with the necessary clearances, allows a maximum of four 20' x 8' x 8' containers to be stowed longitudinally. (Longitudinal clearances are discussed in Section II-2-c).

The number of cells per row is restricted by maximum beam considerations (harbor and canal clearance requirements). In the current study, the number of cells per row is limited to a maximum of nine; however, the algorithm can accommodate any specified number of cells per row.

If refrigerated containers are carried, suitable access has to be provided so that the machinery end of each refrigerator container can be reached for repairs and power connection with the ship's electrical system. This requirement results in either a longer hold or fewer container rows per hold. The former modification can be incorporated in the existing algorithm by simply adjusting the longitudinal clearances. If refrigerated containers are carried, the engine room length, machinery and fuel weight must also be adjusted to allow for additional electrical power consumption.

In the current study, the containers are assumed to be:

i) 20' x 8' x 8' in size

ii) Non-refrigerated

iii) Stowed with their longest dimension in the fore and aft direction.

iv) Stowed up to six high in the hold (A.S.A. standard).

v) Stowed with up to four rows per hold (floodable length limitation).

vi) Stowed with up to nine cells per row (beam limitation).

d) Deck Stowage of Containers

It is highly desirable to be able to load containers on deck as part of the ship's normal cargo since they increase earning capacity without increasing the ship's volumetric requirements. The extent to which they can be stowed on deck is governed by the following considerations:

i) Owner's requirements for container protection from salt water damage.

ii) Ship stability (particularily if no permanent ballast is to be carried).

iii) Visibility problems especially with the bridge located aft.

iv) Crane height: If a shore based crane is used, the maximum height to which containers could be stowed on deck will depend upon both the distance from the water at high tide to the crane boom as well as on the ship's draft and freeboard. If shipboard cranes are used, the higher the containers are stacked above deck, the larger and heavier the shipboard crane becomes, further aggravating the stability problem.

v) Security as sea. It is necessary to secure the deck containers in order to prevent toppling and shifting due to ship's motion and to restrain undue racking of the lowest layer of deck containers. Satisfactory ways of securing at sea are the following:

1) A rigid cell structure built up above the deck.
2) Lashing the containers with wire ropes.
3) Structural frames interposed between layers of containers to which the containers are tied and which in turn are restrained by structural buttresses at the vessel's side.

These securing techniques become quite complex if the number of container layers above deck exceeds two.

vi) Hatch covers. Hatch covers on the weather deck covering all cells in the hold are usually of the lift-on/lift-off steel pontoon type. Pontoon covers have the advantage of occupying no deck space when open since they are stowed upon adjacent hatch covers or upon deck containers of an adjacent hatch not being worked at the time. They are lifted by the crane handling the containers. For easy handling of the hatch covers, the hatch opening should be subdivided into separate sections by longitudinal and transverse hatch support girders, the locations of which will depend upon the layout of the hold. Each of these sections is then covered by a single pontoon of a reasonable size which can be handled quite easily.

The hatch covers must be designed to withstand the concentrated loads imposed by the deck containers. To ensure reasonable plate thickness, the number of container layers above deck is usually limited to two. Finally, the hatch cover must be adequately stiffened to permit lifting by the ends with the crane. This stiffening may increase the thickness of the pontoon cover. The overall pontoon thickness used in this study is four inches when one layer of containers is carried above deck and six inches when two layers of containers are carried above deck.

All facts considered, the number of container layers above deck is limited to two in the examples of this report; however, the algorithm is such that any number can be specified and the correct design will be generated. Furthermore, the common practice of stowing containers with the same number of cells per row and rows per hold, above deck as in the hold, is adhered to in the algorithm of this report.

e) Machinery Location

Because of the fixed container shape, the extremities of a normal ship form are unsuitable for container stowage. Therefore, the machinery in containerships is normally located aft. Other factors favoring this location are:

i) It permits structural continuity in the vicinity of amidships which provides better strength characteristics.

ii) An unbroken sweep of cargo hatches makes the cargo handling easier.

iii) If a shipboard crane is used, one crane can suffice for the whole operation.

iv) The shaft alley is eliminated.

v) Soot corrosion of the tops of deck-stowed containers is practically eliminated thus reducing maintenance costs.

The factors not favoring this location are:

i) Trim problems especially in the lightship condition (in the operation of containerships, this condition is very rarely encountered as loading and unloading is done simultaneously).

ii) Machinery arrangements, particularly piping, are often awkward because of severe shaping of the hull.

iii) The required midship section modulus is higher for a machinery-aft vessel, resulting in higher steel weight and cost.

All facts considered, the advantages of placing the machinery aft in containerships outweigh the disadvantages and it is so located in the studies of this report.

f) <u>Other Cargos</u>

i) General dry cargo. Although the holds at the ship's forward extremity are inefficient for container stowage, this location would be satisfactory for general cargo, handled by conventional unloading gear. However, mixing of cargoes usually results in a greater turn around time because of the inherent inefficiency in dry cargo handling techniques.

ii) Cargo oil. Since containers can be stowed only as far outboard as the edge of the hatch opening, the space outboard to the shell* could be utilized as cargo oil tanks or ballast tanks. The spaces available for these purposes are: 1) the wing tanks, excluding the 8 feet immediately below the weather deck used as a continuous fore and aft passage way, 2) the part of the double bottom not required for fuel oil and ballast and 3) the deep tanks in the forward and aft holds. The problems encountered when cargo oil is carried are: 1) increased turn around time, 2) increased cargo handling costs and 3) increased power requirements due to increased displacement.

All facts considered, no cargo other than that in containers will be carried in the examples of this study. If other cargos are to be carried, modifications must be made in the present algorithm to account for these changes.

f) Required Stability

The required GM at sea for an ordinary cargo ship, may be determined by establishing an upper limit to the angle of heel caused by wind forces or by unsymmetrical flooding in the event of damage. Since a containership has a larger windsail area than an ordinary cargo ship and since it has large wing tanks which may be empty, it may require a larger GM at sea than an ordinary cargo ship. Examination of existing containership designs indicates a minimum allowable, at sea, GM_T value of 4% of the beam

---

*A certain minimum width of deck plating is needed between the outboard edge of the hatch and the shell of the ship for structural reasons. (see Section II-3-b).

i.e.:

$$GM_a \geq .04B \tag{11}$$

where: GM is the actual GM as calculated by Equ. 43.

The GM_a in port for a containership may have to be larger than at sea if shipboard cranes are utilized. This arises from the possibility of large heeling moments when the cranes are fully extended with a load suspended. Ref. [6] suggests a maximum allowable angle of heel of 5° to prevent jamming of the containers in their guides as they are being loaded. However, this port requirement can be met by pumping ballast on board* in port in the ample tankage that is available on containerships. Following loading operations, this ballast can be discharged.

2. Container Block Dimensions

The container block is defined as that part of the below deck volume of a container ship which has sufficient length, width and depth to house the number of containers specified by the owner minus the number of containers which are to be carried above deck.

The following factors enter into the determination of the container block dimensions:

a) Container Distribution

The specification of container distribution includes the

---

* This ballast should not be associated in any way with the item called Ballast Weight, see Equ. 30, in the printout of the algorithm. The latter weight is the difference between the required and the available displacement (see Equ. 30) which the algorithm attemps to minimize (see Section III).

following:

i) number of layers below deck (Section II-1-c)

ii) number of layers above the deck (Section II-1-d)

iii) number of cells per row (Section II-1-c)

iv) number of rows per hold (Section II-1-c)

It is not feasible to predetermine the optimum container distribution. However, because of the restrictions described in Section II-1-c and d there are only a very limited number of distributions possible for a specified number of containers. With the current algorithm, the designer must systematically try each of the several possible distributions until the optimum one is found.

b) Shape Coefficient

The shape coefficient is the ratio of the number of containers that can be housed inside of a ship shaped block to the number of containers that could be housed within a cubic block of the same dimensions with no shape. Typical values of the shape coefficient from Ref. [5] are as follows:

i) 0.85 - 0.90 for an all containership with machinery aft.

ii) 0.95 - 0.98 for a ship with a dry cargo hold forward and machinery af

iii) 0.80 - 0.83 for an all containership with machinery amidships.

The upper value of each range of values in the preceding is applicable for full ships carrying small containers while the lower value of each range is applicable for fine ships carrying large containers. Values used in the sample studies of this report are given in Table 5.

Table 5

Shape Coefficient

Range of Prismatic Coef. C_p	20' x 8' x 8' containers	30' x 8' 8' containers	40' x 8' x 8" containers
.48 - .50	.87	.86	.85
.50 - .52	.88	.87	.86
.59 - .54	.89	.88	.87
.54 - .56	.90	.89	.88
.56 - .56		.90	.89
.58 - .60			.90

c) Hold Length

To allow for clearances and structure, the hold length must be a minimum of 15% greater than the number of rows per hold (specified in the distribution) times the length of each container. The hold length must also be a multiple of the transverse frame spacing of the ship which is assumed at a standard value of 30 inches. Thus, the total hold lengths for 20 foot containers are as follows:

one row per hold: 25' - 0"
two rows per hold: 47' - 6"
three rows per hold: 70' - 0'
four rows per hold:* 92' - 6"

The length of a hold in the forward end of the ship might be slightly different from a typical hold amidships because of the reduced frame spacing towards the ends of the ship. This could be taken account of by adjusting the longitudinal clearances to correspond to the combined frame spacing. In the present study, this modification is not made because of its neglible effect in the determination of the total container block length.

d) Hold Width (Container Block Width)

The container block width between longitudinal bulkheads (identical to hold width) is slightly greater than the number of cells per row times the container width owing to loading target area requirements between containers and clearances for longitudinal hatch beams. If there are an even number of cells per row, a single centerline hatch

---

*This is the maximum number of rows of 20 foot containers that can be stowed in a hold due to floodable length considerations (see Section II-1-c) beam is sufficient while if there are an odd number of cells per row, two longitudinal hatch beams are required for symmetry. The width of a typical hatch beam is taken as about 12 inches.

The hold width may be computed as follows:

$$\text{Hold width (in feet)} = NCR * CW + \frac{NCR * TCBC}{12} + EO * FW \qquad (12)$$

where:

NCR is the number of container cells per row.

CW is the width of each container in feet.

TCBC is the transverse clearance between containers in inches (6 inches for shipboard cranes and 9 inches for shore cranes, see Section II-1-b).

FW is the width of the hatch beam in feet (taken as 1 foot)

EO is a factor equal to 1 if the number of cells per row is even and equal to 2 if the number of cells per row is odd.

For example, for a ship carrying eight foot wide containers with eight cells per row and employing a shore based crane, the hold width is 71 feet.

e) Hold Depth (Container Block Height)

The required hold depth is the number of containers per cell times their height plus allowance for the tank top doubler plate (1 inch) and the clearance between the uppermost container layer below deck and the hatch cover (taken as 4 inches).

f) Container Block Length

The following example will illustrate how container block length may be determined given the information assumed known at this stage of the design procedure:

Given:

i) total number of containers to be carried - 700
ii) container dimensions - 20' x 8' x 8' (see Section II-1-a)
iii) shape factor - 0.90 (see Table 5)
iv) layers below deck - 6 (see Section II-1-a)
v) layers above deck - 2 (see Section II-1-d)
vi) cells per row - 7 (see Section II-1-c-vi)
vii) rows per hold - 4 (see Section II-1-c-v)

Solution Stpes:

1) $\frac{700}{7 \times 8 \times 0.90} \approx 14$ rows

2) This required three holds of four rows each and one hold of two rows.

3) Total length of three four row holds = 92.5 x 3 = 277.5' (see II-2-c)

Total length of one two row hold = 47.6 (see II-2-c)

Total container block length = 325.1

3. Container Ship Principle Dimensions

a) Ship Length.

As noted in the introduction, Equ. (1), the ship length, LBP* is

---

* The length between perpendiculars, LBP, is taken as 98.6% of the water line length designated, L, in this report. (13a)

is one of the independent variables determined by the outcome of the random search process. However, the ship length so determined must be equal to or larger than the minimum required ship length which is taken as the sum of the parts:

$$\text{LBP} \geqq \text{container block length} + \text{machinery space length} + \text{fore and aft peak tanks.} \qquad (13)$$

The last item is taken as .09 LBP. The container block length is as determined in the previous section. The length of an engine room aft with gear turbines is derived from the following empirical formula:

$$\text{Machine Space Length (feet)} = 60 + \text{SHP} \times 10^{-3} \text{ with boilers aft of the engine} \qquad (14)$$

where:

SHP is the required installed power

The algorithm of this study incorporates a check to insure that only values of ship length satisfying Equ. (13) are accepted in any sampling cycle.

b) Beam (B).

The beam selected must be such as to leave sufficient deck width outboard of the container hold for strength purposes. According to Ref. [5] , 7' - 6" of deck plating on each side of the container hold should be adequate while according to [6] , deck plating having a total width equal to 20% of B is acceptable. However, there are containerships in operation in which the total deck plating width is as small as 14.1% of B. [6]

For the purposes of this report, a minimum deck plating width of 17' - 0" is used for nine container cells per row, 15' - 0" for eight container cells per row and 13' - 0" for seven container cells per row. Using Equ. 12, the minimum ship beam is then:

$$
\begin{aligned}
B &\geq 76.25' \text{ for seven cells per row} \\
B &\geq 86.00' \text{ for eight cells per row} \qquad (15) \\
B &\geq 97.75 \text{ for nine cells per row}
\end{aligned}
$$

c) <u>Depth at Side, D.</u>

The depth at side to the uppermost continuous(freeboard) deck of a containership is a function of the following five items:

i) Double bottom height (DBH).

This can be determined using Table 4 of [7] ; however, this height can be less with special justification. For the usual containership arrangements, the values of [7] are too large, hence the following figures are used in this study:

54 inches for ships having 8 container cells per row

48 inches for ships having 7 container cells per row

ii) Center Strake thickness.

This can be determined from the formula:

Center Strake thickness = 0.52 + (LBP - 440)/ 1250 + 0.08 in.

which corresponds approximately to the values for center strake thickness obtained from Table 4 of [7].

iii) Container Block Height (See II-2-e)

iv) Camber

The deck camber of containerships (if any) increases linearly to its maximum value at the side of the hatch opening. For this study, a three inch camber is used.

v) Hatch Coaming Height

Hatch coaming height can be determined using [7] . An increased hatch coaming height saves steel weight and reduces depth at side so it is customary to use hatch coaming heights larger than required by [7] . For a containership the upper value of the hatch coaming height is limited by stability and cargo handling considerations primarily. For this study, a value of 36" is used.

With knowledge of the preceding five items, the hull depth, D, at side is given by:

D = Double bottom height + Center strake thickness + Container block height* - Camber - Hatch coaming height. (16)

4. Structural Considerations

The basic requirements in the structural design of a ship are to provide sufficient hull section modulus for hull bending (specified by the rules of [7]) and to prevent excessive deflections due to twisting and racking. As far as section modulus is concerned in the design of a containership, the large longitudinally continuous hatch opening in the weather

---

*Doubler plate thickness and vertical clearance tolerance are included in the container block height.

deck is compensated for by longitudinal bulkheads provided at each side of the hold together with heavy deck and shear strakes. Longitudinal framing, below the deck outboard of the hold and in the double bottom, also aids in achieving the required sections modulus.

While longitudinal framing is desirable, below deck and in the double bottom, to provide the necessary sectional modulus, transverse framing is desirable in the wing tanks for the following reasons:

i) Transverse framing on the side shell is easier to weld at the extremities of the cargo hold where the narrowness of the wing tanks would make the welding of longitudinal frames difficult.

ii) If cargo oil is carried in the wing tanks, they are far easier to clean and maintain if they are transversely framed.

iii) Transverse framing provides racking strength.

All facts considered, the following structural arrangements are adopted for the containership studies of this report:

i) Longitudinal framing in the double bottom and below the main deck.

ii) Longitudinal bulkheads at each side of the hold.

iii) Transverse framing on the longitudinal bulkheads and side shell.

iv) Transverse bulkheads, web frames and web rings as required for torsional and racking rigidity.

v) Heavy deck plating and heavy sheer strakes.

5. Other Empirical Equations Used in This Containership Study.

The empirical equations presented in this section form the basis for the computations in subareas of the ship design process not discussed in previous sections. Because there are no published data concerning weights and costs for containerships, many of the same empirical equations in these design subareas had to be used in the present study as were used in Ref.[8] and subsequently in Ref. [3] for the more common merchant ship type*. All of the empirical equations given in this section may be numerically solved in each sampling cycle on the basis of:

i) Values of independent variables calculated at the begining of each sampling cycle by the exponential random search technique.

ii) Information already derived in previous sections of this report.

This information is summarized in Table 6.

a) Freeboard (All freeboard dimensions are in inches)

i) Available freeboard (F_a)

$$F_a = 12[D - (0.25 + T)] \qquad (17a)$$

Equation 17a assumes a 3 inch margin line and that the uppermost continuous deck is the freeboard deck.

ii) Required freeboard (F_r)

for $L \leq 400$ feet

---

*This is the major short coming of this report; unfortunately the designers of containerships have been reluctant to release these data.

TABLE 6 - SUMMARY OF ITEMS NEEDED TO SOLVE EMPIRICAL EQUATIONS OF SECTION II-5

TEM	SYMBOL	DISCUSSED IN SECTION	RELATIONSHIP TO INDEPENDENT VARIABLES	RESTRICTIONS ON VALUES
hip Length	L	II-3-a	Equ. 1	Equ. 2(upper and lower limit) Equ. 4 & 6(upper and lower lim Equ. 13(lower limit)
hip Beam	B	II-3-b	—	Equ. 15(determines beam provid Equs. (3) and (11) are satisfi
hip Depth	D	II-3-c	—	Equ. 16(determines depth provi Equs. (2) and (17e) are satisf
hip Draft	T	I	Equ. 8	No direct constraints placed c are in this report. Indirect straints imposed by Equ. 3-7.
rismatic Coef.	C_p	I	x_2	Equ. (5)
idship Coef.	C_m	I	x_4	Equ. (7)
lock Coef.	C_b	-	$(x_2)(x_4)$	Equ. (5) and (7)
Ship Displacement	Δ	I	x_1	Equ. (6),(10a) and (30)

$$F_r = 4.21 + 3.59 \left(\frac{L}{100}\right) + 3.71 \left(\frac{L}{100}\right)^2 \qquad (17b)$$

for 400 feet $< L \leq$ 750 feet

$$F_r = -77.67 + 42.58 \left(\frac{L}{100}\right) - 0.60 \left(\frac{L}{100}\right)^2 - 0.08 \left(\frac{L}{100}\right)^3 \qquad (17c)$$

for 750 $< L$

$$F_r = 0.2322 * L \qquad (17d)$$

Equations (17) are based on [9] .

In order for any design to be accepted $F_a \geq F_r$ (17e)

b) <u>Power</u>

i) Frictional resistance coefficient, C_F.

$$C_F = \frac{0.75}{(\log_{10} R_e - 2)^2} \qquad (18)$$

where:

R_e is the Reynolds number for salt water at $59^{\circ}F$, R_e is given by:

$$R_e = 1.3177 \times 10^5 \, (L \times V) \qquad (19)$$

where:

L is in feet

V is in knots

ii) Correlation allowance, ΔC_F.

$$\Delta C_F = 0.0004 \qquad (20)$$

iii) Residual resistance coefficient, C_R.

C_R is obtained from Taylor Standard Series subprogram discussed in Appendix I and II.

iv) Bare hull, $(EHP)_{bh}$

$$(EHP)_{bh} = \rho/2\ (WS_f)\ (\Delta \times L)^{\frac{1}{2}}\ (V^3)\ (C_F + C_R + \Delta C_F)\ 0.00872 \qquad (21)$$

where:

ρ = mass density at salt water at 59°F = 1.9905

WS_f = wetted surface factor given in Table 7

v) Required Installed SHP

Corrections are applied to the $(EHP)_{bh}$ for appendage resistance, propulsive coefficient, and service margin. The service margin is intended to take account of the effect of rough water, fouling and so on. Assumed values for the foregoing allowances are:

Appendage allowance = 3% of $(EHP)_{bh}$

Propulsive coefficient = 75%

Service margin = 25%

Using these allowances:

$$SHP = K_1\ (EHP)_{bh} \qquad (22)$$

where:

$$K_1 = \frac{1.25 \times 1.03}{0.75} = 1.72$$

c) Weights (all weights are in terms of long tons)

i) Outfit Weight =

$$W_o = 0.15 \left[\frac{(L * B)\ K_9}{100} \right]^{1.60} \qquad (23)$$

where:

K_9 = 0.986

Table 7

Wetted Surface Factor, WS_f

B/T	WS_f
2.25	15.09
2.75	15.05
3.25	15.12
3.75	15.29

The values given in this table are applicable to the Taylor's Standard Series with $C_m = 0.925$. The small variation of WS_f with C_m is not accounted for in the algorithm of this report.

ii) Steel Weight =

$$W_s = 2.107 \left[\frac{L(B-D) * K_9}{100} \right]^{1.19} \tag{24}$$

iii) Wet Machinery Weight =

$$W_m = 7.18 \; [SHP]^{0.495} \tag{25}$$

(the individual items included in each of the three preceding weight groups are given in [10] .)

iv) Weight of fuel oil (W_f) required to sail the specified distance, E plus 10% allowance, at a given speed V:

$$W_f = \frac{(1.10) \; E * SHP * FR}{2240 * V} \tag{26}$$

where:

FR is the approximate fuel rate

$$FR = \frac{0.5 \; SHP}{SHP - 855} \tag{27}$$

v) Miscellaneous deadweight = W_x = 300 (28)

vi) Payload weight = W_p = N x WEC (29)

vii) Ballast weight = $W_b = \Delta - W_o - W_s - W_m - W_f - W_x - W_p \geq 0$ (30)

Any values of $\Delta = x_1$ not satisfying Equ. (30) are rejected by the algorithm.

d) Volumes (all volumes given in cubic feet)

i) Approximate fuel-oil capacity in the double bottom $(Vol)_{db}$:

$$(Vol)_{db} = (K_9 * L) * B * DBH * (0.69 * C_b) \tag{31}$$

C_b is the block coefficient at LWL: factor 69% is a correction for structure in inner bottom and a correction to obtain C_b at the WL height equal to tank top height. (Fuel-oil stowage factor is 37.2 cu. ft./ton).

ii) Approximate fuel-oil settler-tank capacity $(\text{Vol})_{st}$

$$(\text{Vol})_{st} \geq 5600 \text{ cu. ft.} \tag{32}$$

(In the algorithm $(\text{Vol})_{db} + (\text{Vol})_{st}$ must be equal to or greater than $37.2\ W_f$; if it is less than $37.2\ W_f$, then Vol_{st} is increased beyond 5600 cu. ft. until $(\text{Vol})_{db} + (\text{Vol})_{st} = 37.2\ W_f$).

e) <u>Actual Stability</u>

i) Approximation to the transverse inertia coefficient (α) of the design load water plane:

$$\alpha = 0.0957\ C_p - 0.0122 \tag{33}$$

ii) Approximation to the KG of steel:

$$KG_s = K_3 D \tag{34}$$

where:
$K_3 = 0.61$

iii) Approximation to the KG of outfit:

$$KG_o = K_4 D \tag{35}$$

where:
$K_4 = 1.00$

iv) Approximation to the KG of miscellaneous deadweight:

$$KG_x = K_8 D \tag{36}$$

where:
$K_8 = 1.00$

v) Approximation to KG of fuel oil in steeler tanks:

$$KG_{st} = DBH + 0.60\ (D-DBH) \tag{37}$$

vi) Approximation to KG of fuel oil and ballast in double bottom. For normal ships this is taken as 2/3 of the tank top height:

$$KG_{db} = 0.67 * DBH \tag{38}$$

vii) Approximation to machinery KG, with boilers full and for conventional arrangement for steam-turbine plant:

$$KG_{m} = 0.55\ D \tag{39}$$

viii) Approximation to the vertical moment $(M)_{pb}$ of payload below deck:

In Section (II-2-f) the number of rows (NROWS) required to accomodate the containers was calculated.

Let NI = (NROWS)(NCC)(NCR)

where: NI is the number of containers that could be housed within the container block dimensions if the shape coefficient (see Section II-2-b) were 1.0.

NCC is the number of containers per column.

NCR is the number of container cells per row.

and NLOST = NI - N.

where: NLOST is the number of containers lost due to hull shape.

N is the required number of containers to be carried per trip.

It is assumed that:

1) the integer part of 25% of NLOST is lost from layer, 1 (NLOST 1),
2) the integer part of 25% of NLOST is lost from layer, 2 (NLOST 2),
3) the integer part of 20% of NLOST is lost from layer, 3 (NLOST 3).

Let NREM = (.3 NLOST)/(NCC-3)

If NREM is an integer, it represents the number of containers lost from each of the remaining layers i.e.:

layer(4), layer(5), ---- layer (NCC-1), layer (NCC)

If NREM is not an integer, the integer part of NREM, [NREM] represents the number of containers lost from layer(5) layer(6), ---- layer (NCC). and the number of containers lost from layer, 4 (NLOST 4) is given by:

(NLOST 4) = (NLOST)-(NLOST 1)-(NLOST 2)-(NLOST 3) -[NREM] (NCC-4).

The number of containers (CONT(i)) in each layer, i, for i = 1....4, is now determined as follows:

i = 1) CONT 1 = (NCR)(NROWS)-NLOST 1
i = 2) CONT 2 = (NCR)(NROWS)-NLOST 2
i = 3) CONT 3 = (NCR)(NROWS)-NLOST 3
i = 4) CONT 4 = (NCR)(NROWS)-NLOST 4

The number of containers (CONT) in layers, j, for j = 5...NCCBD is now determined as follows:

$$\text{CONT} = (\text{NCR})(\text{NROWS})(\text{NCCBD}-4) - [\text{NREM}](\text{NCCBD}-4)^{*}$$

where:

NCCBD = number of containers per column below deck.

Let: LEVER = double bottom height + center strake thickness + double thickness.

then:

$$\begin{aligned}(M)_{p_b} = {} & (\text{CONT }1)(\text{LEVER} + \tfrac{1}{2}\text{CH})\ \text{WEC} + \\ & (\text{CONT }2)(\text{LEVER} + \tfrac{3}{2}\text{CH})\ \text{WEC} + \\ & (\text{CONT }3)(\text{LEVER} + \tfrac{5}{2}\text{CH})\ \text{WEC} + \\ & (\text{CONT }4)(\text{LEVER} + \tfrac{7}{2}\text{CH})\ \text{WEC} + \\ & (\text{CONT})(\text{LEVER} + 4\text{CH} + (\text{NCCBD} - 4)/2)\ \text{WEC}\end{aligned} \qquad (40)$$

where:

CH is the container height in feet and WEC is the weight of each container and its cargo.

ix) Approximation to the vertical moment $(M)_{pa}$ of payload above deck.

Let: (CONT A) be the number of containers carried above deck

then (CONT A) = N - (CONT 1)-(CONT 2)-(CONT 3)-(CONT 4)-

(CONT) (CONT)

---

*Expression evaluating CONT implies that NCCBD $\geq$ 4

Let:

$$\text{LEVER A} = D + (CA + HCH + HC)/12 + \Big[(NCC - NCCBD)(CH)\Big]/2$$

where:

CA is the camber in inches

HCH is the hatch coaming height in inches

HC is the hatch cover height in inches

then $(M)_{pa} = (\text{CONT A})(\text{LEVER A})(\text{WEC})$ (41)

x) Approximation to the center of buoyancy (KB)

$$KB = K_2 T \tag{42}$$

where:

$K_2 = 0.54$

xi)

$$GM_a = KB + \alpha \frac{LB^3}{35\Delta} - \Big(W_s\ KG_s + W_o\ KG_o + W_m\ KG_m + \frac{(Vol)_{st}}{37.2}\ KG_{st} + \left(W_f - \frac{(Vol)_{st}}{37.2} + W_b\right) KG_{db} + W_x\ KG_x + (M)_{pb} + (M)_{pa}\Big) / \Delta \tag{43}$$

xii) Is $GM_a \geqq GM_r$? (43a)

f) <u>Costs (all costs are given in dollars</u>)

i) Outfit Costs (C_o).

for $0 \leqq W_o \leqq 1400$ tons

$$C_o = 4\left[1100 - 0.043\, W_o + (0.112 * 10^{-3})\, W_o^2 - (0.1323 * 10^{-6})\, W_o^3\right] W_o \qquad (44)$$

for $1400 < W_o < 2600$ tons

$$C_o = 4\left[2430 - 1.928\, W_o + (0.722 * 10^{-3})\, W_o^2 - (0.091 * 10^{-6})\, W_o^3\right] W_o \qquad (45)$$

for $W_o \geqq 2600$ tons

$$C_o = 4 * 698.8\, W_o \qquad (46)$$

ii) Steel Cost (C_s).

$$C_s = 4 * \left[218.4 - 21.38\, W_s * 10^{-3} + 2.061\, W_s^2 * 10^{-6} - 0.1149\, W_s^3 * 10^{-9}\right] W_s \qquad (47)$$

Equ. 47 is restricted to $0 \leqq W_s \leqq 8000$ long tons

iii) Machinery Cost (C_M).

for SHP $\leqq 13000$

$$C_M = 4\left[137.7 - \frac{SHP}{75.32 + \frac{SHP}{100}\, 5.92}\right] SHP \qquad (48)$$

for SHP $\geqq 13000$

$$C_M = 4\left[\frac{SHP}{3.249\,\frac{SHP}{100} - 173.95}\right] SHP \qquad (48a)$$

iv) Ballast Weight Cost (C_B)

$$C_B = 1000 * W_b \qquad (49)$$

v) Annual fuel cost, C_f

$$C_f = K_{10}\, K_5\, W_f\, V/E \qquad (50)$$

K_5 = 13.90 \$

K_{10} = Ship use factor, its value depends on the following assumptions.

Let:

V = required speed (owner's requirement)

E = range between fueling ports (owner's requirement)

W_f = tons fuel oil needed for steaming a distance 1.10E, this includes a 10% margin for reserve.

U_f = percentage of time (year) when the ship is operating at full power.

U_r = percentage of time (year) when the ship is operating at reduced power.

r = ratio of "fuel consumption at reduced power" to "fuel consumption at full power" $(0 < r < 1)$.

Then:

Tons of fuel oil required for one hour's operation at full power $= \frac{W_f * V}{1.10E}$

Hours per year at full power = 365 x 24 U_f.

Hours per year at reduced power = 365 x 24 U_r.

Tons of fuel required for one hour's operation at reduced power $= (\frac{W_f\ V}{1.10E})r$

Therefore, the total fuel oil required per year:

$$(W)_{fy} = \frac{365 \times 24}{1.10} \times (U_f + U_r r) \frac{W_f V}{E} = K_{10} \frac{W_f V}{E}$$

hence:

$$K_{10} = 7971.6 \, (U_f + U_r r)$$

Numerical example in deriving K_{10}

For a conventional containership carrying 800 containers per trip at 25 knots for 3,000 miles, the owner can anticipate 49 one way trips in a 343 operational day year.

So for such a case:

$$U_f = \frac{(49)(3000)}{(25)(24)(343)} = .71$$

$$U_r = .25$$

$$\text{Dead Plant} = .04$$

From [8] r for steam turbines is approximately equal to .042. So:

$$K_{10} = 5750$$

vi) Total annual cost.

$$\text{Total annual cost} = c = K_{11} (C_o + C_s + C_M + C_B) + C_f \qquad (51)$$

K_{11} = 0.0704 and is derived as shown below:

$$K_{11} = \frac{(1 + .05)^{25} - .025}{(1 + .05)^{25} - 1} \; .05$$

which assumes:

Straight-line depreciation plus average interest.

25 - year economic life

$2\frac{1}{2}\%$ scrap value

5% interest

III. Containership Optimization Criterion, c.

On the basis of an examination similar to that presented in [3], it was decided that the overall optimization criterion should include two considerations. One of these is the economic criterion (the sum of the yearly fuel costs plus annual depreciation and interest charges). The other is related to the so called ballast weight or excess displacement (see Equ. 30). In contrast with [3] the latter consideration, instead of being treated as a separate term in the overall optimization criterion, has been incorporated into the economic criterion in this report by regarding the excess displacement as permanent ballast and including its cost in the total ship cost as indicated by Equ. 49 and 51.

The selected optimization criterion is therefore the total annual cost, c, as defined by Equ. 51. The optimization technique described in Section 2 of Ref. [3] , applied to the containership design model, seeks to find those values of the independent variables, x_1, x_2, x_3 and x_4 (see Table 1) that will result in a minimum value of c for any given set of owner's requirements (Table 2) and any selected container distribution, that is for:

$$c = f(X, \bar{P}, \bar{D}) \qquad (52)$$

where:

$X = x_1, x_2, \ldots, x_i, \ldots, x_n.$

$\bar{P}$ is a specified set of values of the owner's requirements given in Table 2.

$\bar{D}$ is a specific container distribution (see Section II-2-a)

$$(x_i)_{min} \leqq x_i \leqq (x_i)_{max} \qquad (53)$$

$(x_i)_{min}$ and $(x_i)_{max}$ correspond to the restrictions on the values of each x_i as given by Equs. (2) - (7) and (10a)

and the algorithm seeks to find:

$$c = \text{minimum possible value} \qquad (54)$$

The excess of displacement is combined with the economic criterion for several reasons. One is the intuitive expectation, that the least cost design will be one which has minimum excess displacement. However, this may not be the case. For example, for designs where there is difficulty in satisfying the stability criterion, Equ. 11, it is conceivable that it might be satisfied, at less total annual cost, c, (as defined by Equ. 51) by incorporating permanent fixed ballast rather than by increasing wing tank width beyond the minimum values specified in Section II-3-b. By incorporating the excess ballast in the economic criterion, the outcome of a complete optimization search should reveal this subtle point.

IV. Summary of Containership Optimization Procedure

1. The Five Steps of a Complete Sampling Cycle.

Several modifications to the technique of Ref. [3] had to be made in order to adopt it to the containership design problem. While the general outline of the five basic steps of a complete sampling cycle[1] are the same as discussed in Section 2C of Ref. [3] , there are, nevertheless, some differences. For completeness, these five steps are restated with the necessary modifications:

i) First Step

In the first step, a decision is made whether or not to update the transformation, discussed in ii) below, before it is used to update the rth component of X where:

$$1 \leq r \leq n$$

and n = number of components of X.

ii) Second Step

In the second step the following transformation is used for generating a new value for the rth component of X. This transformation is the same as Equ. 4 of Ref. [3] :

$$x_i = x_i^* + \left[(x_i)_{max} - (x_i)_{min} \right] y^M \qquad (55)$$

where:

The x_i^*'s are the values of x_i found in the previous complete sampling cycle (that is in the 0....k-1 sampling cycles) that yielded the lowest value of c, designated c^*, found so far in the optimi-

---

[1] A complete sampling cycle in the terminology of this report is a sampling cycle in which $c = f(X, \overline{F}, \overline{D})$ is successfully computed. Any sampling cycle may be aborted before c is computed by failure to satisfy the freeboard, displacement and stability conditions imposed by Equs. 17e, 30 and 11. In the terminology of Ref. [3] such an aborted cycle is not called a sampling cycle.

zation procedure.

$$y = 2z - 1 \text{ and } -1 \leqq y \leqq +1$$

z is a random number generated by the algorithm such that:

$$0 \leqq z \leqq 1$$

M is the exponent of the transformation and can have any positive odd value, 1,3... .

When M = 1, the transformation is purely random, while for values of M greater than 1, the search intensity is greater in the vicinity of x_i^*. Ref. [3] suggests that for the first 60% of the total number of sampling cycles in any complete optimization procedure, M should be one, corresponding to a pure random search. Experience with the containership design model shows that the following figures are preferable:

for the first 80% of the sampling loops[1] M = 1
for the subsequent 10% of the sampling loops M = 3
for the subsequent 5% of the sampling loops M = 5
and for the last 5% of the sampling loops M = 7

These figures can be readily changed by the user in the existing algorithm.

The selection of how many x_i's to update in the second step (answer; one) and what values to assign to the x_i's not updated in each sampling cycle[2] (answer; the values associated with those x_i's in the just previous sampling cycle) is made as indicated in the discussion of step 2 of Section 2D of Ref. [3] .

iii) Third Step

Using the values of each x_i as determined in the second step, the

---

[1] A sampling loop consists of somewhere between n and 5n sampling cycles, of which a maximum of n can be complete sampling cycles. (see step iii of this section).

[2] Note the difference in the definition of a sampling cycle between this report and Ref. [3] discussed in the footnote on pg. 46.

optimization criterion, $c = f(X, \bar{\bar{P}}, \bar{\bar{D}})$, is evaluated following the steps outlined in Section IV-2. In the event that a sampling cycle is aborted in this step because of failure to satisfy the freeboard, displacement and stability restrictions imposed by Equs. (17e), (30) and (11), the algorithm returns to step ii) and generates a new value for the x_r being updated in this sampling cycle. It does this up to five times for each x_r. This completes a sampling loop. Thus, a sampling loop may consist of up to 5n aborted sampling cycles. On the other hand, if in the course of updating each x_r, no sampling cycles are aborted, a sampling loop consists of n complete sampling cycles.

iv) Fourth Step

The new c obtained in the third step is compared with c^*, where c^* is the best output of any of the previous sampling cycles. If the new c is better than c^*, c^* takes on the value of the new c and the values of the components of X that resulted in c become the new x_i^*'s. If the new c is worse than the c^* current at the start of the kth sampling cycle, this substitution is skipped.

v) Fifth Step

The condition for termination of the search is examined. Should the termination condition not be satisfied, the search process will repeat steps i) through v); but should the reverse happen, the search will terminate.

The terminating mechanism used in the current algorithm terminates the search when the total number of sampling loops, L, exceeds a certain predetermined number. In this report, L is taken as 1000.

2. Summary of Calculations Involved in Evaluating $c = f(X, \overline{P}, \overline{D})$.

The calculations and the tests for freeboard, displacement and stability involved in evaluating $c = f(X, \overline{P}, \overline{D})$, as discussed in step iii) of Section IV-1, are performed sequentially in the following order: (the equations used in each calculation are referenced parenthetically).

i) Calculate L, LBP, C_v. (1, 13a, 10)
ii) Calculate T. (8)
iii) Calculate D. (16)
iv) Calculate available freeboard, F_a. (17a)
v) Calculate required freeboard, F_r. (17b,c,d)
vi) Is $F_a \geq F_r$? (17e)
vii) Calculate frictional resistance coefficient, C_F. (18)
viii) Calculate residuary resistance coefficient, C_R (using resistance subprogram).
ix) Calculate bare hull EHP_{bh} (21)
x) Calculate SHP (22)
xi) Calculate W_o, W_s, W_m, W_f, W_x, W_p, W_b. (23-30)
xii) Is $W_b \geq 0$? (30)
xiii) Calculate $(Vol)_{db}$ and $(Vol)_{st}$ (31, 32)
xiv) Calculate actual GM_a (33-43)
xv) Calculate required GM_r ($GM_r = 0.04B$)
xvi) Is $GM_a \geq GM_r$? (11 , 43a)
xvii) Calculate Cost (44-51)

3. Preliminary Steps To Be Carried Out Before Starting a Complete Optimization Study.

Before using the algorithm of this report to carry out a complete optimization study for a given set of owner's requirements, $\overline{P}$, the user must make certain selections, carry out certain calculations by hand and use the algorithm to carry out certain preliminary steps. This preliminary work by the user and preliminary steps by the algorithm are discussed in this section.

a) Selection of Container Distribution.

The first selection that must be made by the user is the container distribution, D. If the required number of containers, N, is between 700 and 1000 and if the containers to be carried are 20' x 8' x 8', the following preliminary distribution, $\overline{D}$, may be assumed:

Number of layers below deck (NCCBD) - 6 (see Section II-1-a)
Number of layers above deck - 2 (see Section II-1-d)
Number of cells per row (NCR) - 8 (see Section II-1-c-vi)
Number of rows per hold - 4 (see Section II-1-c-v)

b) Preliminary Hand Calculations

Following the selection of the container distribution, the following calculations should be carried out by hand:

i) Compute minimum ship beam B, (see Equ. 15).

ii) Compute ship depth, D (see Equ. (16) and Section II-3-c).

iii) Compute ship length, L, corresponding to L/D = 14.5 (Equ. 2). This tends to impose an upper limit, L_{max}, on the value that L can assume.

iv) Compute $V/\sqrt{L}$ for the value of L computed in iii). This value of $V/\sqrt{L}$ should be used for $(x_3)_{min}$ provided it is larger than 0.50 (see Equ. 4); if it is smaller than 0.50, then L_{max} should be recomputed using $V/\sqrt{L} = 0.50$.

v) Compute container block length (see Section II-2-f).

vi) Compute ship length, L, using Equ. (13) and (14) for SHP value somewhat less than the anticipated SHP. (e.g. in this study 20,000 SHP was used for a speed of 25 knots), This ship length will correspond to L_{min}.

vii) Compute $V/\sqrt{L}$ for the value of L computed in vi). This value of $V/\sqrt{L}$ should be used for $(x_3)_{max}$ provided its value is less than 1.2 (see Equ. 4); if it is larger than 1.2, then L_{min} should be recomputed using $V/\sqrt{L} = 1.2$.

viii) Compute the upper and lower limits on the draft, T, using ship depth, D, as determined in step ii) and approximating the upper and lower limits on freeboard by using equations 17b, c, and d in association with L_{max} as determined in either step (iii) or (iv) and L_{min} as determined in step (vi) or (vii).

ix) Using the value of B determined in step (i) (or as adjusted in step (x)) and the values of T determined in step (viii), compute the upper and lower values of B/T.

x) If the upper and lower values of B/T computed in step (ix) are grossly outside the values given in Equ. (3), the value of B computed in step (i) should be adjusted by either changing the assumed wing tank width or the container distribution.

In the former case, step (ix) of this section has to be repeated before continuing, while in the latter case, step (i) through (x) of this section have to be repeated.

c) Initial Selections By The User.

The following initial selections should now be made by the user.

i) Select a value for $(x_1)_{min}$ as suggested at the end of Section I.

ii) Select a value for $(x_1)_{max}$ using as a guide, the value of L computed in IV-3-b-iii or IV-3-b-iv and the upper value of C_v given in Equ. 6.

iii) Select an arbitrary value for x_1 between the limits determined in the two preceding steps.

iv) Select a value for $(x_2)_{min}$ using either the lower limit of Equ. 5 or the lower value of the prismatic coefficient given in Table 5 that is associated with the shape coefficient used in step IV-3-b-v; whichever is higher.

v) Select an arbitrary value for x_2 between the upper limit given in Equ. 5 and the lower limit determined in the previous step.

vi) Select an arbitrary value for x_3 between the limits determined in steps iv and vii of Section IV-3-b.

vii) Select an arbitrary value for x_4 between the limits stated in Equ. 7.

d) Preliminary Steps by the Algorithm and User

The following steps may now be carried out by the algorithm:

i) Using the values of x_i selected in steps (iii), (v), (vi) and (vii) of the previous section, the algorithm attempts to evaluate the optimization criterion, $c = f(X,\bar{\bar{P}},\bar{\bar{D}})$, following the steps outlined in Section IV-2. If this attempt is successful the algorithm goes to step (iii) of this section. On the other hand, if the attempt is unsuccessful because of failure to satisfy the freeboard, displacement and stability restrictions imposed by Equs. (17e), (30) and (11), the algorithm goes to step (ii) which carries out what is called the zero sampling loop.

ii) Using Equ. (55)[1], the algorithm generates a new value[2] for x_r, where $r = 1,\ldots,n$. With this updated value for x_r and with values for the remaining x_i's, i.e. $(1,\ldots,r - 1, r + 1,\ldots,n)$ equal to those used in the just previous sampling cycle, the algorithm again attempts to evaluate the optimization criterion $c = f(X, \bar{\bar{P}}, \bar{\bar{D}})$ following the steps outlined in Section IV-2. In the event that this attempt is successful, the algorithm goes to step (iii) of this section. This completes the zero sampling loop. On the other hand, if the attempt is unsuccessful, the algorithm repeats this step, updating each x_r $(r = 1,\ldots,n)$ in turn up to 5 times. If this

---

[1] At this point in the optimization procedure, no values for the x_i^*'s of Equ. 55 have been generated. Therefore, the values of the x_i's selected by the user in Section IV-3-c are used in Equ. 55 in lieu of values for x_i^*.

[2] The first time this step is executed, $r = 1$.

step is executed 5n times and no set of x_i's is found that satisfies the freeboard, displacement and stability restrictions imposed by Equs. (17e), (30) and (11), the algorithm prints an error message and goes to step (iv) of this section. At this point, the zero sampling loop is also completed[1] even though no successful design has been generated.

iii) The set of x_i's that results in the first complete sampling cycle is designated as x_i^* and the value of c calculated in this sampling cycle is designated as c^*. The algorithm then executes steps (i) through (v) of Section IV-1 with L = 20. These 20 additional sampling loops serve to give information that will either validate the selections made in Sections IV-3-a, and IV-3-c or suggest how these selections should be changed. The user should now procede to step (v) of this section.

iv) At this point, no x_i^*'s or c^* have been generated. To permit the algorithm to proceed to sampling loops subsequent to the zero sampling loop, the values of the x_i's selected by the user in Section IV-3-c are again used in Equ. 55 in lieu of values for x_i^*, and c^* is arbitrarily set equal to a very large value; the algorithm then executes steps (i) through (v) of Section IV-1 with L = 20. Although the likelihood is small, it is possible that these 20 additional loops will give information that will help validate the selections made in Sections IV-3-a and IV-3-c or suggest that these selections

---

[1] Note that in the zero sampling loop, somewhere between 1 and 5n sampling cycles are executed, of which only one can be a complete sampling cycle, whereas in sampling loops subsequent to the zeroth one, between n and 5n sampling cycles are executed of which up to n can be complete sampling cycles.

should be changed. If in these 20 additional sampling loops, no set of x_i's is found that satisfies the freeboard, displacement and stability restrictions imposed by Equs. (17e), (30) and (11), the algorithm prints an error message and terminates the search. Failure to satisfy the restrictions of Equs. (17e), (30), and (11) at this point in the optimization procedure signifies either insufficient beam, insufficient depth in relation to ship length, or insufficient displacement. The user at this point, must therefore either:

1. Increase beam, either by increasing the wing tank width or by increasing the number of cells per row. The latter step has the effect of reducing the required container block length and hence the ship length, if the number of containers per cell and per column is not changed. Reducing ship length also has the favorable effect of reducing the required freeboard (Equs. 17b,c and d). Thus, increasing beam by increasing the number of cells per row will improve the chances of a design satisfying the restrictions of both Equ. 11 and 17e.
2. Increase depth by increasing the number of container layers below deck and reducing the number

of container layers above deck. This increases available freeboard with practically no effect on stability.

3. Increase the value for $(x_1)_{min}$. It may be that the restriction imposed by Equ. 30 is aborting the sampling cycles. If this is the case, increasing the value of $(x_1)_{min}$ will help satisfy this restriction.

Following these changes, the user should repeat the steps outlined in Section IV-3-b, c and d. This process should be repeated until the algorithm successfully calculates, at least, one value of c.

v) From the information gained from either step (iii) or (iv), the user should now be able to select values for the ranges of the independent variables, which will assure satisfaction of the restrictions imposed by Equs. (17e), (30) and (11).Using as values for the initial set of x_i's, the x_i^*'s obtained from the last complete sampling cycle of the 21 preliminary sampling loops[1], the algorithm executes steps (i) through (v) of Section IV-1 until the termination mechanism described in Section IV-1-v is satisfied.

---

[1] If, in this step, the user does not select a set of values of x_i^*'s for the initial values of x_i, the algorithm may again execute the zeroth loop, step (ii) of this section. Using a known good set of x_i's avoids this possibility.

V. Applications and Results

Example results obtained from using the algorithm of this report are given in this section. For the fixed set of owner's requirements and the other fixed input data given in Table 8, the algorithm was used to determine the effect on the characteristics of optimized containership designs of changes in wing tank width, shape coefficient and distribution of containers above and below deck. The example results are shown in Table 9. Obviously changes in many other parameters could have been studied, but in the time available only the results shown in Table 9 were obtained.

Table 9 shows the expected result that increased wing tank increases stability and increases ship cost. Unfortunately, the wing tank width was not reduced sufficiently to create stability critical designs ($GM_a \leqq 0.04$). Hence, the subtle effect of increased beam versus increased ballast weight discussed in Section III is not demonstrated in Table 9.

The slightly increased ship cost associated with the increased shape coefficient shown in Table 9 is brought about by the necessity for specifying a higher minimum value for C_p, $(x_2)_{min}$, in the algorithm, in accordance with steps IV-3-c-iv. The higher C_p value increases power requirements which increases machinery cost.

Table 9 shows that for the two cases examined, it is preferable to stow more containers below deck and fewer above deck from the point of view of the optimization criterion used in this report,c. Whether this is true generally, remains a question for future study.

The very low values of C_m for the ships with six container layers below deck and one above is of interest. This apparently arises from the beneficial effect on power of reducing the B/T ratio (decreasing C_m permits an increase in draft). For the ships with five container layers below deck and two above, the maximum draft is severely restricted by freeboard considerations, hence the optimum C_m value is much higher. It is possible that if the data of Table 7 were augmented to include the effect of C_m on wetted surface, that the tendency towards very low optimum C_m values, where there is no restriction on draft, would be partially mitigated.

Owner's Specifications:

Service speed, (V)	25 knots
Range, (E)	3000 miles
Total number of containers, (N)	800
Maximum load of each container when fully loaded, (WEC)	15.00 tons
Container length, (CL)	20.00 feet
Container width, (CW)	8.00 feet
Container height, (CH)	8.00 feet

Container Distribution:

Number of rows per hold	4.0
Number of containers per column	7.0
Number of cells per row	8.0

Parameters Controlling the Exponential Search:

Percentage of loops where M = 1, $(1/L)_1$	0.80
Percentage of loops where M = 3, $(1/L)_2$	0.10
Percentage of loops where M = 5,7 $(1/L)_{3,4}$	0.05
Total number of sampling loops, (L)	1000

Auxiliary Input Data:

KB/T	0.54
KG(steel)/D	0.61
KG(outfit, stores)/D	1.00
LBP/LWL	0.986
GM_T/B	0.040
SHP/EHP	1.720
Fuel Cost	13.90 dollars/ton
Ship use factor, K_{10}	5750

Longitudinal Clearance per Hold:

1 row per hold	5.0 feet
2 rows per hold	7.5 feet
3 rows per hold	10.0 feet
4 rows per hold	12.5 feet

Transverse Clearances:

Between Containers	9.0 inches
Flange width on longitudinals	1.0 foot

Vertical Clearances:

Doubler thickness	1.0 inch
Hatch coaming height	36.0 inches
Tolerances	4.0 inches
Camber	3.0 inches
Double bottom height	54.0 inches
Hatch cover thickness (2 container layers on deck)	6.0 inches
Hatch cover thickness (1 container layer on deck)	4.0 inches

TABLE 9

Effect of Varying Wing Tank Width, Container Distribution And Shape Coefficient on Optimum Containership Designs.

Container Distribution						
No. layers below deck	6	6	6	5	5	6
No. layers above deck	1	1	1	2	2	1
No. rows per hold	4	4	4	4	4	4
No. cells per row	8	8	8	8	8	8
Wing Tank Width, ft.	18	19	20	20	20	20
Shape Coefficient	0.87	0.87	0.87	0.87	0.90	0.90
$\bar{X}$ Δ, tons	23,570	23,827	23,970	23,770	23,550	23,900
C_p	0.519	0.522	0.519	0.534	0.544	.541
$V/\sqrt{L}$	1.053	1.051	1.045	1.043	1.053	1.051
C_m	0.829	0.818	0.813	0.985	0.972	0.802
LBP (opt.) ft.	556	558	565	567	556	558
LBP (min.) ft.	541	541	541	544	517	515
B ft.	890	900	91.0	91.0	91.0	91.0
D ft.	50.0	50.0	50.0	42.0	42.0	50.0
T ft.	38.4	38.9	38.7	30.7	30.9	38.0
LBP/D	11.1	11.2	11.3	13.5	13.2	11.2
B/T	2.30	2.32	2.35	2.96	2.95	2.39
SHP	37,190	37,350	37,130	39,700	40,640	39,050
W_s tons	5,962	5,832	5,767	5,588	5,461	5,880
W_o tons	3,272	3,143	3,061	3,279	3,179	3,197
W_m tons	1,314	1,316	1,313	1,357	1,373	1,346
W_f tons	1,121	1,126	1,120	1,195	1,223	1,176
W_x tons	300	300	300	300	300	300
W_p tons	12,000	12,000	12,000	12,000	12,000	12,000
W_b tons	2	110	9	49	18	2
F_a inches	132	130	132	132	130	140
$F_a - F_r$ inches	+2.5	+0.9	+0.6	+0.2	+1.6	+10.8
GM_a/B	0.056	0.065	0.067	0.060	0.067	0.078
$\bar{c}$ in 10^6 \$/yr.	1.938	1.966	1.979	2.047	2.048	2.017

VI. Conclusions and Recommendations

The new technique for optimizing multi-dimensional functions, developed in Refs. [1],[2],[3],[11] and [12] . has been successfully applied in this report to the containership preliminary design problem.

The nature of the empirical equations given in Section II-5 strongly suggests that a more refined mathematical model should be developed so that required changes in structural scantlings may be reflected in the ship weight and cost equations.

The technique used in this study as well as in Ref. [3] , [8] , [11] and [12] for the calculation of the residual resistance coefficient can be improved. A more elegant procedure, for example, would be to employ a regression equation when calculating the residual resistance coefficient. Such a regression equation would serve to alleviate somewhat, the restrictions on the values that some of the independent variables can assume as given in Equs. (3) to (6).

Future development of the research described in this report will include consideration of ship beam as a random variable thus increasing the number of random variables to five. In treating beam as a random variable, its values will be severely restricted to those appropriate to the selected container distribution.

Finally, the methods developed in this study for solving the problem of discrete ship dimensions can be readily adopted to the problem of discrete power-plant sizes. This adoption will be the subject of future work by the author.

LIST OF REFERENCES

1. D.C. Karnopp, "Search Theory Applied to Parameter Scan Optimization Problems", PhD. Thesis, M.I.T. Department of Mechanical Engineering, 1961.

2. D.A. Gall, "Minimizing Ship Motions", PhD Thesis, M.I.T. Department of Mechanical Engineering, 1964.

3. P. Mandel and R. Leopold, "Optimization Methods Applied to Ship Design", S.N.A.M.E., 1966.

4. M. Gertler, "A Reanalysis of the Original Test Data for the Taylor Standard Series", D.T.M.B. Report 806, 1954.

5. R.J. Scott, "Containership Design", S.N.A.M.E., 1962.

6. J.J. Henry and H.J. Karsch, "Container Ships", S.N.A.M.E., 1966

7. American Bureau of Shipping, 1961

8. R.D. Murphy, D.J. Sabat, and R.J. Taylor, "Least Cost Ship Characteristics by Computer Techniques", Marine Technology, 1965.

9. U.S. Coast Guard, "Load Line Regulations", 1963

10. "Classification of Weights", U.S. Department of Commerce, 1962.

11. R. Leopold, "Mathematical Optimization Methods Applied to Ship Design", M.I.T. Department of Naval Architecture and Marine Engineering, Report No. 65-8, 1965.

12. D.S. Somekh, "Optimum Oil Tanker Design by a Convergent Random Search Technique", M.I.T. Department of Naval Architecture and Marine Engineering, Report 66-2, 1966.

13. D.A. Argyriadis, "Cargo Container Ships", I.N.A., 1959.

14. L.A. Harlander, "Engineering Development of a Container System for the West Coast - Hawaian Trade", S.N.A.M.E., 1960.

15. L.A. Harlander, "Further Developments of a Container System for the West Coast-Hawaian Trade", S.N.A.M.E. 1961.

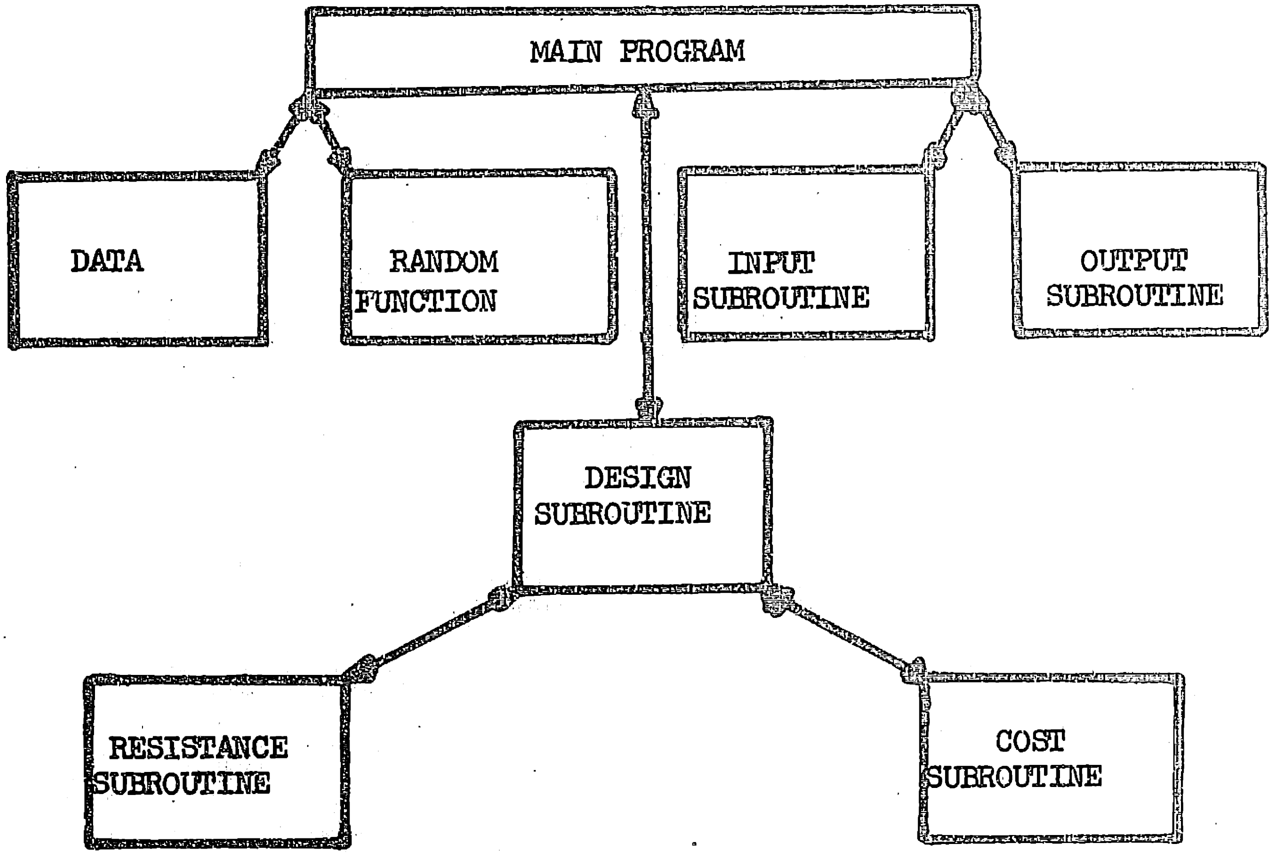
APPENDIX I

The Fortran listing of the main program, subroutines and functions used in this study are included in this Appendix.

The library functions used are the LOG and SQRT and thier listings are not included.

Below, the general flow chart for the algorithm is shown diagramatically.

GENERAL FLOW CHART



```
C     STEAM TURBINES. CONTAINER SHIP
      COMMON TIME,M,MA,MB,MC,N,XMIN,XMAX,CR,
     1V,RA,WEC,CNT,CNV,CNA,CNLPH,CNVB,CLE,CBR,CHE,DBH,
     2CLEAR1,CLEAR2,CLEAR3,CLEAR4,CBC,FW,WTW,DT,HHC,TOL,CAMBER,HATC
     3FK,FK1,FK2,FK3,FK4,FK5,FK8,FK9,FK10,FK12
      DIMENSION TIME(4),XMIN(4),XMAX(4),CR(6210)
      DIMENSION XBI(4),XBJ(4),XBL(4),CRR(6210)
C     INITIALIZES RANDOM NUMBER GENERATOR
      YYY=RAND(-1.0)
C     READ TAYLOR'S RESIDUAL RESISTANCE COEFFICIENTS
      READ 20 , (CRR(I), I=1,6210)
   20 FORMAT (21X,6F7.3)
      MM=1
      NN=1035
      DO 21 J=1,6
      LL=1
      DO 1 I=MM,NN
      IK=J+(LL-1)*6
      CR(I)=CRR(IK)
    1 LL=LL+1
      MM=1035+MM
      NN=1035+NN
   21 CONTINUE
   10 CONTINUE
      CALL INPUT(XBI)
C     ESTIMATE NUMBER OF CONTAINERS PER IDEAL ROW
      CNPR=CNA*CNV
C     ESTIMATE NUMBER OF ROWS REQUIRED
      ROWSN=1.
  113 CNRI=ROWSN*CNPR
      CNRA=CNRI*FK
      NCRA=CNRA
      NCT=CNT
      IF(NCRA-NCT)111,814,814
  111 ROWSN=ROWSN+1.
      GO TO 113
C     DETERMINE BLOCK LENGTH
  814 IF(CNLPH-3.)159,160,161
  159 HOLDSN=ROWSN/2.
      NHOLDS=HOLDSN
      HOLDN=NHOLDS
      IF(HOLDSN-HOLDN)401,151,152
  151 BLOCKL=HOLDN*(2.*CLE+CLEAR2)
      GO TO 118
  152 BLOCKL=HOLDN*(2.*CLE+CLEAR2)+CLE+CLEAR1
      GO TO 118
  160 HOLDSN=ROWSN/3.
      NHOLDS=HOLDSN
      HOLDN=NHOLDS
      IF(HOLDSN-HOLDN)401,114,115
  114 BLOCKL=HOLDN*(3.*CLE+CLEAR3)
      GO TO 118
  115 IF((HOLDSN-HOLDN)-0.5)116,401,117
```

```
  116 BLOCKL=HOLDN*(3.*CLE+CLEAR3)+CLE+CLEAR1
      GO TO 118
  117 BLOCKL=HOLDN*(3.*CLE+CLEAR3)+2.*CLE+CLEAR2
      GO TO 118
  161 HOLDSN=ROWSN/4.
      NHOLDS=HOLDSN
      HOLDN=NHOLDS
      IF (HOLDSN-HOLDN)401,153,154
  153 BLOCKL=HOLDN*(4.*CLE+CLEAR4)
      GO TO 118
  154 IF((HOLDSN-HOLDN)-0.25)401,155,156
  155 BLOCKL=HOLDN*(4.*CLE+CLEAR4)+CLE+CLEAR1
      GO TO 118
  156 IF((HOLDSN-HOLDN)-0.50)401,157,158
  157 BLOCKL=HOLDN*(4.*CLE+CLEAR4)+2.*CLE+CLEAR2
      GO TO 118
  158 BLOCKL=HOLDN*(4.*CLE+CLEAR4)+3.*CLE+CLEAR3
  118 CONTINUE
C     VAN WIDTH
      VANW=CNA*CBR
C     REQUIRED CLEARANCE FOR CELLS
      CLEAR=(CNA*CBC)/12.
C     REQUIRED CLEARANCE FOR FLANGES
      EOT=CNA/2.
      LEOT=EOT
      EOTL=LEOT
      IF(EOT-EOTL)401,800,801
  800 EVOD=0.0
      GO TO 999
  801 EVOD=1.0
  999 FLANGE=((EVOD+1.0)*FW)
C     BLOCK WIDTH
      BLOCKW=VANW+CLEAR+FLANGE
C     BEAM
      B=BLOCKW+WTW
C     MOMENT CONSIDERATION
      CNLOST=CNRI-CNT
      NCLOST=CNLOST
      NLOST1=NCLOST/4
      NLOST2=NCLOST/4
      NLOST3=NCLOST/5
      N123=NLOST1+NLOST2+NLOST3
      NREM=NCLOST-N123
      NCV=CNV
      NREMV=NCV-3
      NPLAY=NREM/NREMV
      NREMA=NPLAY*NREMV
      IF(NREM-NREMA)401,191,192
  191 NLOST4=NPLAY
      GO TO 193
  192 NLOST4=NPLAY+NREM-NREMA
  193 CONTINUE
      CLOST1=NLOST1
      CLOST2=NLOST2
```

```
      CLOST3=NLOST3
      CLOST4=NLOST4
      PLAYER=NPLAY
      CPLYR=CNA*ROWSN
      CONT1=CPLYR-CLOST1
      CONT2=CPLYR-CLOST2
      CONT3=CPLYR-CLOST3
      CONT4=CPLYR-CLOST4
      CONT=CPLYR-PLAYER
   75 CALL DESIGN(XBI(1),XBI(2),XBI(3),XBI(4),
     1FL,FLBP,B,H,D,BH,FLD,CV,CB,REQDIS,ACT,
     2FA,FAR,DELFA,PTB,DELPTB,BM,FKB,FKM,FKG,GM,GMB,GMBR,DELGMB,
     3WMA,WO,WS,WM,WF,RPLOAD,DELDIS,CONT1,CONT2,CONT3,CONT4,CONT,
     4CS,CFS,CF,ACRINT,SHP,ROWSN,NCRA,BLOCKL,REQLBP,FLBPR)
      CVV=CV*1000.
      IF(CVV-1.)74,1020,1020
 1020 IF(CVV-6.)300,300,74
  300 IF(FLBPR-FLBP)301,301,74
  301 IF(BH-2.25)74,302,302
  302 IF(BH-3.75)303,303,74
  303 IF(FLD-10.0)74,304,304
  304 IF(FLD-14.5)305,305,74
  305 IF(DELFA)306,306,74
  306 IF(REQLBP-FLBP)307,307,74
  307 IF(DELDIS)74,308,308
  308 IF(DELGMB)29,29,74
C     MODIFY INITIAL DIS,CP,V/SQRT(L),CAMID
   74 L=4
      DO 76 I=1,L
      ISTAB=0
   72 XBJ(I)=XBI(I)+(XMAX(I)-XMIN(I))*((2.0*RAND(0.0)-1.0)**M)
      DO 55 LL=1,L
      IF(XBJ(LL))55,56,55
   56 XBJ(LL)=XBI(LL)
   55 CONTINUE
      FL=(V/XBJ(3))**2
      CV=(XBJ(1)*35.)/FL**3
      CVV=(XBJ(1)*35.*1000.)/FL**3
      IF(CVV-1.)72,1030,1030
 1030 IF(CVV-5.)77,77,72
   77 IF(XBJ(I)-XMIN(I))72,78,78
   78 IF(XMAX(I)-XBJ(I))72,309,309
  309 FLBPR=(BLOCKL+80.)/0.91
      FLBP=FL*FK9
      IF(FLBPR-FLBP)310,310,72
  310 H=(XBJ(1)*35.)/(FLBP*B*XBJ(4)*XBJ(2))
      BH=B/H
      IF(BH-2.25)72,311,311
  311 IF(BH-3.75)68,68,72
   68 CALL DESIGN(XBJ(1),XBJ(2),XBJ(3),XBJ(4),
     1FL,FLBP,B,H,D,BH,FLD,CV,CB,REQDIS,ACT,
     2FA,FAR,DELFA,PTB,DELPTB,BM,FKB,FKM,FKG,GM,GMB,GMBR,DELGMB,
     3WMA,WO,WS,WM,WF,RPLOAD,DELDIS,CONT1,CONT2,CONT3,CONT4,CONT,
     4CS,CFS,CF,ACRINT,SHP,ROWSN,NCRA,BLOCKL,REQLBP,FLBPR)
```

```
      IF(FLD-10.)49,312,312
  312 IF(FLD-14.5)313,313,49
  313 IF(DELFA)314,314,49
  314 IF(REQLBP-FLBP)315,315,49
  315 IF(DELDIS)49,316,316
  316 IF(DELGMB)37,37,49
   49 ISTAB=ISTAB+1
      IF(ISTAB-5)72,76,76
   37 ISTAB=0
      GO TO 82
   76 CONTINUE
      ISTAB=0
      PRINT 400
  400 FORMAT(38H1INITIAL PARAMETER CHOICE ~~POOR~~. MODIFY)
      AFXI=5000000.0
      GO TO 1015
   82 DO 71 I=1,L
   71 XBI(I)=XBJ(I)
C     EVALUATION OF CRITERION
   29 DISDEL=DELDIS/1000.0
      AFXI=DELPTB
      INDEX=-1
      NCYCLE=0
      CALL OUTPUT(XBI(1),XBI(2),XBI(3),XBI(4),
     1FL,FLBP,B,D,H,CB,NCYCLE, CV,FLD,BH,CNT,NCRA,ROWSN,
     2FK1,SHP,ACT,ACRINT,CF,CS,WS,WO,WM,WF,RPLOAD,WMA,REQDIS,DELDIS,
     3FAR,FA,DELFA,FKB,FKM,FKG,GM,GMBR,PTB,INDEX)
C     NUMBER OF SAMPLINGS
 1015 AN=N
C     NUMBER OF SAMPLINGS WITH EXPONENT M EQUAL TO 1,3,5,7 RESPECTIV
      IIA=TIME(1)*AN
      IIB=TIME(2)*AN
      IIC=TIME(3)*AN
      IID=N-IIA-IIB-IIC
C     COUNTER DETERMINING THE VALUE OF EXPONENT M
      KK=-2
C     COUNTER OF CYCLES WITH M=1 ,3,5,7,
      JJ=IIA
C     COUNTER FOR CONSECUTIVE IMPROVEMENTS
      IJI=-1
C     COUNTER OF NUMBER OF CHANGES OF EACH PARAMETER IN ANY LOOP
      ISTAB=0
      DO 2 J=1,N
      NCYCLE=J
      IF (J-JJ)93,93,30
   30 KK=KK+1
      IF(KK)31,32,33
   31 JJ=IIB+IIA
      M=MA
      GO TO 93
   32 JJ=IIC+IIB+IIA
      M=MB
      GO TO 93
```

```
33    JJ=IID+IIC+IIB+IIA
      M=MC
93    CONTINUE
      L=4
      DO 5 I=1,L
      ISTAB=0
3     XBL(I)=XBI(I)+(XMAX(I)-XMIN(I))*((2.0*RAND(0.0)-1.0)**M)
      DO 52 LL=1,L
      IF(XBL(LL))52,51,52
51    YBL(LL)=XBI(LL)
52    CONTINUE
      FL=(V/XBL(3))**2
      CV=(XBL(1)*35.)/FL**3
      CVV=(XBL(1)*35.*1000.)/FL**3
      IF(CVV-1.)3,2000,2000
2000  IF (CVV-6.0) 17,17,3
17    IF(XBL(I)-XMIN(I))3,7,7
 7    IF(XMAX(I)-XBL(I))3,500,500
 500  FLBP=FL*FK9
      IF(FLBPR-FLBP)501,501,3
 501  H=(XBL(1)*35.)/(FLBP*B*XBL(4)*XBL(2))
      BH=B/H
      IF(BH-2.25)3,502,502
 502  IF(BH-3.75)6,6,3
 6    CALL DESIGN(XBL(1),XBL(2),XBL(3),XBL(4),
     1FL,FLBP,B,H,D,BH,FLD,CV,CB,REQDIS,ACT,
     2FA,FAR,DELFA,PTB,DELPTB,BM,FKB,FKM,FKG,GM,GMB,GMBR,DELGMB,
     3WMA,WO,WS,WM,WF,RPLOAD,DELDIS,CONT1,CONT2,CONT3,CONT4,CONT,
     4CS,CFS,CF,ACRINT,SHP,ROWSN,NCRA,BLOCKL,REQLBP,FLBPR)
      IF(FLD-10.)39,503,503
 503  IF(FLD-14.5)504,504,39
 504  IF(DELFA)505,505,39
 505  IF(REQLBP-FLBP)506,506,39
 506  IF(DELDIS)39,507,507
 507  IF(DELGMB)27,27,39
 39   ISTAB=ISTAB+1
      IF(ISTAB-5)3,5,5
  27  ISTAB=0
      DISDEL=DELDIS/1000.0
      AFXL=DELPTB
      IF(AFXL-AFXI) 4,5,5
 4    IJI=IJI+1
      XBI(I)=XBL(I)
      AFXI=AFXL
      AA=XBL(1)
      BB=XBL(2)
      CC=XBL(3)
      DD=XBL(4)
      INDEX=0
      CALL OUTPUT(XBL(1),XBL(2),XBL(3),XBL(4),
     1FL,FLBP,B,D,H,CB,NCYCLE, CV,FLD,BH,CNT,NCRA,ROWSN,
     2FK1,SHP,ACT,ACRINT,CF,CS,WS,WO,WM,WF,RPLOAD,WMA,REQDIS,DELDIS,
     3FAR,FA,DELFA,FKB,FKM,FKG,GM,GMBR,PTB,INDEX)
```

```
5     CONTINUE
 2    CONTINUE
      IF(IJI)600,601,601
  600 PRINT 1000
 1000 FORMAT(25H1RANGE CHOICE POOR.MODIFY)
      GO TO 401
  601 CONTINUE
      CALL DESIGN(AA,BB,CC,DD,
     1FL,FLBP,B,H,D,BH,FLD,CV,CB,REQDIS,ACT,
     2FA,FAR,DELFA,PTB,DELPTB,BM,FKB,FKM,FKG,GM,GMB,GMBR,DELGMB,
     3WMA,WO,WS,WM,WF,RPLOAD,DELDIS,CONT1,CONT2,CONT3,CONT4,CONT,
     4CS,CFS,CF,ACRINT,SHP,ROWSN,NCRA,BLOCKL,REQLBP,FLBPR)
       INDEX=1
       CALL OUTPUT(AA,BB,CC,DD,
     1FL,FLBP,B,D,H,CB,NCYCLE, CV,FLD,BH,CNT,NCRA,ROWSN,
     2FK1,SHP,ACT,ACRINT,CF,CS,WS,WO,WM,WF,RPLOAD,WMA,REQDIS,DELDIS,
     3FAR,FA,DELFA,FKB,FKM,FKG,GM,GMBR,PTB,INDEX)
  401  CONTINUE
       GO TO 10
       END
```

```
      SUBROUTINE INPUT(XBI)
      DIMENSION TIME(4),XMIN(4),XMAX(4),CR(6210)
      DIMENSION XBI(4)
      COMMON TIME,M,MA,MB,MC,N,XMIN,XMAX,CR,
     1V,RA,WEC,CNT,CNV,CNA,CNLPH,CNVB,CLE,CBF,CHE,DBH,
     2CLEAR1,CLEAR2,CLEAR3,CLEAR4,CBC,FW,WTW,DT,HHC,TOL,CAMBER,HATCH
     3FK,FK1,FK2,FK3,FK4,FK5,FK8,FK9,FK10,FK12
      K=2
      L=4
      WRITE OUTPUT TAPE K,1
    1 FORMAT(46H1INPUT PARAMETERS FOR SHIP DESIGN OPTIMIZATION//)
      WRITE OUTPUT TAPE K,20
 20   FORMAT(46H PARAMETERS CONTROLLING THE EXPONENTIAL SEARCH)
      READINPUT TAPE L,48,TIME(1),TIME(2),TIME(3),TIME(4)
   48 FORMAT(1H ,8X,F4.2,10X,F4.2,10X,F4.2,10X,F4.2)
      WRITE OUTPUT TAPE K,18,TIME(1),TIME(2),TIME(3),TIME(4)
   18 FORMAT(9H TIME(1)=,F4.2,2X,8HTIME(2)=,F4.2,2X,
     18HTIME(3)=,F4.2,2X,8HTIME(4)=,F4.2)
      READ INPUT TAPE L,3,M,MA,MB,MC,N
    3 FORMAT(1H ,2X,I2,5X,I2,5X,I2,5X,I2,22X,I4)
      WRITE OUTPUT TAPE K,2,M,MA,MB,MC,N
    2 FORMAT(3H M=,I2,2X,3HMA=,I2,2X,3HMB=,I2,2X,3HMC=,I2,
     12X,20HNUMBER OF SAMPLINGS=,I4)
      WRITE OUTPUT TAPE K,4
    4 FORMAT(15H DISPLACEMENT, ,29H  MINIMUM   MAXIMUM   INITIAL)
      READ INPUT TAPE L,5,XMIN(1),XMAX(1),XBI(1)
    5 FORMAT(1H ,14X,F8.1,2X,F8.1,2X,F8.1)
      WRITE OUTPUT TAPE K,5,XMIN(1),XMAX(1),XBI(1)
      WRITE OUTPUT TAPE K,6
    6 FORMAT(15H CP            , ,29H  MINIMUM   MAXIMUM   INITIAL)
      READ   INPUT TAPE L,7,XMIN(2),XMAX(2),XBI(2)
      WRITE OUTPUT TAPE K,7,XMIN(2),XMAX(2),XBI(2)
    7 FORMAT(1H ,14X,F8.5,2X,F8.5,2X,F8.5)
      WRITE OUTPUT TAPE K,8
    8 FORMAT(15H V/SQRT(L)     , ,29H  MINIMUM   MAXIMUM   INITIAL)
      READ   INPUT TAPE L,7,XMIN(3),XMAX(3),XBI(3)
      WRITE OUTPUT TAPE K,7,XMIN(3),XMAX(3),XBI(3)
      WRITE OUTPUT TAPE K,9
    9 FORMAT(15H CX            , ,29H  MINIMUM   MAXIMUM   INITIAL)
      READ INPUT   TAPE L,7,XMIN(4),XMAX(4),XBI(4)
      WRITE OUTPUT TAPE K,7,XMIN(4),XMAX(4),XBI(4)
      WRITE OUTPUT TAPE K,10
   10 FORMAT(22H OWNERS SPECIFICATIONS)
      READ INPUT TAPE L,41,V,RA
   41 FORMAT(1H ,14X,F5.2,18X,F8.1)
      WRITE OUTPUT TAPE K,11,V,RA
   11 FORMAT(15H SERVICE SPEED=,F5.2,2X,6HKNOTS,,
     14X,6HRANGE=,F8.1,2X,5HMILES)
      READ   INPUT TAPE L,51,CNT,WEC
   51 FORMAT(1H ,27X,F6.1,30X,F5.2)
      WRITE OUTPUT TAPE K,21,CNT,WEC
   21 FORMAT(28H TOTAL NUMBER OF CONTAINERS=,F6.1,1H,,
     14X,25HWEIGHT OF EACH CONTAINER=,F5.2,4HTONS)
```

```
      WRITE OUTPUT TAPE K,22
   22 FORMAT(21H CONTAINER DIMENSIONS)
      READ   INPUT TAPE L,53,CLE,CBR,CHE
   53 FORMAT(1H ,7X,F5.2,13X,F4.2,14X,F4.2)
      WRITE OUTPUT TAPE K,23,CLE,CBR,CHE
   23 FORMAT(8H LENGTH=,F5.2,3HFT,,
     14X,6HWIDTH=,F4.2,3HFT,,4X,7HHEIGHT=,F4.2,2HFT)
      WRITE OUTPUT TAPE K,24
   24 FORMAT(23H CONTAINER DISTRIBUTION)
      READ   INPUT TAPE L,55,CNLPH
   55 FORMAT(1H ,34X,F3.1)
      WRITE OUTPUT TAPE K,25,CNLPH
   25 FORMAT(45H NUMBER OF CONTAINER ROWS PER HOLD [illegible]=,F3.1)
      READ   INPUT TAPE L,56,CNV
   56 FORMAT(1H ,32X,F3.1)
      WRITE OUTPUT TAPE K,26,CNV
   26 FORMAT(33H NUMBER OF CONTAINERS PER COLUMN=,F3.1)
      READ   INPUT TAPE L,57,CNVB
   57 FORMAT(1H ,43X,F3.1)
      WRITE OUTPUT TAPE K,27,CNVB
   27 FORMAT(44H NUMBER OF CONTAINERS PER COLUMN BELOW DECK=,F3.1)
      READ   INPUT TAPE L,58,CNA
   58 FORMAT(1H ,29X,F3.1)
      WRITE OUTPUT TAPE K,28,CNA
   28 FORMAT(30H NUMBER OF CONTAINER CELLS PER ROW =, F3.1)
      WRITE OUTPUT TAPE K,12
   12 FORMAT(21H AUXILIARY INPUT DATA)
      READ   INPUT TAPE L,43,FK2,FK3,FK4,FK8
   43 FORMAT(1H ,5X,F4.2,14X,F4.2,15X,F4.2,15X,F4.2)
      WRITE OUTPUT TAPE K,13,FK2,FK3,FK4,FK8
   13 FORMAT(6H KB/H=,F4.2,2X,12HKG(STEEL)/D=,F4.2,2X,
     113HKG(OUTFIT)/D=,F4.2,2X,13HKG(STORES)/D=,F4.2)
      READ INPUT TAPE L,44,FK9,FK12,FK1,FK5
   44 FORMAT(1H ,8X,F5.3,7X,F5.3,10X,F5.3,19X,F5.2)
      WRITE OUTPUT TAPE K,14,FK9,FK12,FK1,FK5
   14 FORMAT(9H LBP/LWL=,F5.3,2X,5HGM/B=,F5.3,2X,
     18HSHP/EHP=,F5.3,2X17HFUEL COST IN $  =,F5.2)
      READ   INPUT TAPE L,45,FK10,FK
   45 FORMAT(1H ,16X,F7.1,39X,F5.3)
      WRITE OUTPUT TAPE K,15,FK10,FK
   15 FORMAT(17H SHIP USE FACTOR=,F7.1,1X,
     138HACTUAL TO IDEAL CONTAINER SPACE RATIO=,F5.3)
      WRITE OUTPUT TAPE K,16
   16 FORMAT(24H LONGITUDINAL CLEARANCES)
      READ   INPUT TAPE L,47,CLEAR1,CLEAR2
   47 FORMAT(1H ,26X,F5.2,32X,F5.2)
      WRITE OUTPUT TAPE K,17,CLEAR1,CLEAR2
   17 FORMAT(27H 1 CONTAINER ROW  PER HOLD=,F5.2,4H FT.,2X,
     126H2 CONTAINER ROWS PER HOLD=,F5.2,4H FT.)
      READ   INPUT TAPE L,47,CLEAR3,CLEAR4
      WRITE OUTPUT TAPE K,19,CLEAR3,CLEAR4
   19 FORMAT(27H 3 CONTAINER ROWS PER HOLD=,F5.2,4H FT.,2X,
     126H4 CONTAINER ROWS PER HOLD=,F5.2,4H FT.)
      WRITE OUTPUT TAPE K,30
   30 FORMAT(22H TRANSVERSE CLEARANCES)
      READ   INPUT TAPE L,61,CBC,FW,WTW
   61 FORMAT(1H ,19X,F4.1,18X,F4.2,21X,F5.2)
```

```
31 FORMAT(20H BETWEEN CONTAINERS=,F4.1,4H IN.,1X,13HFLANGE WIDTH=,
  1F4.2,4H FT.,1X,16HWING TANK WIDTH=,F5.2,4H FT.)
   WRITE OUTPUT TAPE K,32
32 FORMAT(20H VERTICAL CLEARANCES)
   READ   INPUT TAPE L,63,DT,HHC,TOL
63 FORMAT(1H ,8X,F5.3,20X,F5.2,16X,F5.2)
   WRITE OUTPUT TAPE K,33,DT,HHC,TOL
33 FORMAT(9H DOUBLER=,F5.3,4H IN.,2X,14HHATCH COAMING=,F5.2,4H IN.
  12X,10HTOLERANCE=,F5.2,4H IN.)
   READ   INPUT TAPE L,64,CAMBER,HATCHH,DBH
64 FORMAT(1H ,8X,F5.2,20X,F5.2,12X,F5.2)
   WRITE OUTPUT TAPE K,34,CAMBER,HATCHH,DBH
34 FORMAT(9H CAMBER =,F5.2,4H IN.,2X,14HHATCH COVER  =,F5.2,4H IN.
  1,10HDB HEIGHT=,F5.2,4H IN.,/1H1)
   RETURN
   END
```

```
      FUNCTION RAND(X)
      IF (X) 10,20,20
20    RN = RHO * RAND
      RN1 = MODF(RN,BN)
      RAND = RN1 / BN
      RETURN
10    RHO = 7.0 ** 13.
      BN = 10. ** 10.
      RAND = -X
      GO TO 20
      END
```

```
      SUBROUTINE DESIGN(DIS,CP,VL,CXAP,
     1FL,FLBP,B,H,D,BH,FLD,CV,CB,REQDIS,ACT,
     2FA,FAR,DELFA,PTB,DELPTB,BM,FKB,FKM,FKG,GM,GMB,GMBR,DELGMB,
     3WMA,WO,WS,WM,WF,RPLOAD,DELDIS,CONT1,CONT2,CONT3,CONT4,CONT,
     4CS,CFS,CF,ACRINT,SHP,ROWSN,NCRA,BLOCKL,REQLBP,FLBPR)
      COMMON TIME,M,MA,MB,MC,N,XMIN,XMAX,CR,
     1V,RA,WEC,CNT,CNV,CNA,CNLPH,CNVB,CLE,CBR,CHE,DBH,
     2CLEAR1,CLEAR2,CLEAR3,CLEAR4,CBC,FW,WTW,DT,HHC,TOL,CAMBER,HATCHH,
     3FK,FK1,FK2,FK3,FK4,FK5,FK8,FK9,FK10,FK12
      DIMENSION TIME(4),XMIN(4),XMAX(4),CR(6210)
C     COMPUTE L.W.L.,L.B.P.,CV
      FL=(V/VL)**2
      FLBP=FL*FK9
      CV=(DIS*35.)/FL**3
      CVV=CV*1000.
      IF(CVV-1.)13,100,100
  100 IF (CVV-6.) 2,2,13
C     ROUGH CHECK FOR LENGTH
    2 FLBPRA=BLOCKL+80.
      FLBPR=FLBPRA/0.91
      IF(FLBPR-FLBP)5,5,13
C     DRAFT
    5 H=(DIS*35.)/(FL*FK9*B*CXAP*CP)
C     CHECK IF BEAM RATIO IS INSIDE REQUIRED RANGE
      BH=B/H
      IF(BH-2.25)13,32,32
   32 IF(BH-3.75)33,33,13
C     CENTER GIRDER DEPTH
   33 DBHFT=DBH/12.0
C     CENTER STRAKE THICKNESS
      CST=0.52+(FL*FK9-440.)/1250.+0.08
C     HEIGHT OF CONTAINER COLUMN IN THE HOLD
      HC=CNVB*CHE*12.
C     DEPTH
      D=(DBH+CST+DT+HC-HHC+TOL-CAMBER)/12.
C     CHECK IF LENGTH  DEPTH RATIO IS INSIDE RANGE
      FLD=FL*FK9/D
      IF(FLD-10.)13,34,34
   34 IF(FLD-14.5)35,35,13
C     CHECK IF FREEBOARD IS ADEQUATE
   35 IF(FL-400.)85,85,86
 85   FA=4.21+0.0359*FL+0.000371*FL**2
      GO TO 89
 86   IF(FL-750.) 87,87,90
 87   FA=-77.67+.4258*FL-.00006*FL**2-0.00000008*FL**3
      GO TO 89
 90   FA=.2322*FL
 89   FAR=12.0*(D-(H+0.25))
      DELFA=FA-FAR
      IF(DELFA) 12,12,13
C     COMPUTE WETTED SURFACE COEFFICIENT
 12   CS1=15.086
      CS2=15.046
```

```
      CS3=15.115
      CS4=15.293
      IF(BH-2.75)6,7,8
 6    ABH=2.75-BH
      CS=CS2-((CS2-CS1)*ABH)/0.5
      GO TO 9
 7    CS=CS2
      GO TO 9
 8    IF(BH-3.25)66,77,88
 66   ABH=3.25-BH
      CS=CS3-((CS3-CS2)*ABH)/0.5
      GO TO 9
 77   CS=CS3
      GO TO 9
 88   ABH=3.75-BH
      CS=CS4-((CS4-CS3)*ABH)/0.5
C     COMPUTE SHP  REQUIRED
 9    RE=131778.0*V*FL
      FRE=LOGF(RE)/2.30259-2.0
      CFS=0.075/(FRE**2)
      CF=CFS+0.0004
      CALL RESIS(CV,BH,CP,VL,    ACRINT)
      ACT=CF+ACRINT
      CON=FK1*V**3*CS*0.0087184*SQRTF(FL*DIS)
      SHP=CON*ACT
C     FINAL LENGTH CHECK
      ELENG=60.+0.001*SHP
      REQLBP=(BLOCKL+ELENG)/0.91
      IF(REQLBP-FL*FK9)10,10,13
C     ESTIMATE WEIGHT
   10 WMA=300.0
      WO=0.15*(FL*FK9*B*.01)**1.6
      WS=2.107*(FL*FK9*(B+D)*.01)**1.19
      WM=7.18*(SHP)**.495
      WF=.0002455*RA*SHP**2/(V*(SHP-855.0))
      RPLOAD=CNT*WEC
      REQDIS=WMA+WO+WS+WM+WF+RPLOAD
      DELDIS=DIS-REQDIS
      IF(DELDIS)13,11,11
C     ESTIMATION OF VOLUME
   11 CB=CXAP*CP
      VPFB=FK9*FL*B*DBHFT*0.69*CB
      WPFB=VPFB/37.2
      WFR=WF-150.0
      IF(WPFB-WFR)71,62,62
   71 WFD=WF-WPFB
      IF(WFD-150.0)62,63,63
   62 WFD=150.
      WFB=WFR
      GO TO 64
   63 WFB=WPFB
   64 CONTINUE
```

```
C     CHECK IF STABILITY IS ADEQUATE
      ALFA=0.0957*CP-0.0122
      BM=(ALFA*FL*B**3)/(35.*DIS)
      FKB=FK2*H
      FKM=BM+FKB
      FKGS=FK3*D
      FMS=FKGS*WS
      FKGO=FK4*D
      FMO=FKGO*WO
      FKGM=0.55*D
      FMM=FKGM*WM
      FKGX=FK8*D
      FMX=FKGX*WMA
      FKGFB=0.67*DBHFT
      FMFB=FKGFB*WFB
      FKGFD=DBHFT+0.60(D-DBHFT)
      FMFD=FKGFD*WFD
      FBAL=FKGFB*DELDIS
      BASE=(DBH+CST+DT)/12.
      ARM1=BASE+CHE/2.
      ADARM=CHE
      CM1=ARM1*CONT1*WEC
      ARM2=ARM1+ADARM
      CM2=ARM2*CONT2*WEC
      ARM3=ARM2+ADARM
      CM3=ARM3*CONT3*WEC
      ARM4=ARM3+ADARM
      CM4=ARM4*CONT4*WEC
      CMBT=CM1+CM2+CM3+CM4
      ARM=ARM4
      CNVBT=CNVB
   94 IF(CNVBT-4.)13,95,96
   95 CMB=CMBT
      GO TO 97
   96 ARM=ARM+ADARM
      CM=ARM*CONT*WEC
      CMBT=CMBT+CM
      CNVBT=CNVBT-1.
      GO TO 94
   97 CONTINUE
      BASEA=D+(CAMBER+HHC+HATCHH+DT)/12.
      CNVA=CNV-CNVB
      ARMA=BASEA+(CNVA*CHE)/2.
      CMA=ARMA*CONT*CNVA*WEC
      FMC=CMB+CMA
      FKG=(FMS+FMO+FMM+FMC+FMX+FMFD+FMFB+FBAL)/DIS
      GM=FKM-FKG
      GMBR=FK12
      GMB=GM/B
      DELGMB=GMBR-GMB
      IF (DELGMB) 30,30,13
   30 CONTINUE
      CALL COST(WO,WS,SHP,WF,V,RA,PTB,FK10,FK5,DELPTB,DELDIS)
   13 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RESIS(CV,BH,CP,VL,    ACRINT)
      COMMON TIME,M,MA,MB,MC,N,XMIN,XMAX,CR,
     1V,RA,WEC,CNT,CNV,CNA,CNLPH,CNVB,CLE,CBR,CHE,DBH,
     2CLEAR1,CLEAR2,CLEAR3,CLEAR4,CBC,FW,WTW,DT,HHC,TOL,CAMBER,HATCHI
     3FK,FK1,FK2,FK3,FK4,FK5,FK8,FK9,FK10,FK12
      DIMENSION TIME(4),XMIN(4),XMAX(4),CR(6210)
      XPFF(II,JJ,KK)=23*15*(II-1)+15*(JJ-1)+KK
      XPPFF(II,JJ,KK)=1035+XPFF(II,JJ,KK)
      CONTINUE
C     COMPUTATION OF RESIDUAL RESISTANCE
      CVV=CV*1000.0
      IF(CVV-2.0)89,90,90
 89   M=0
      CVD=CVV-1.0
      GO TO 4
 90   IF(CVV-3.0)91,92,92
 91   M=1
      CVD=CVV-2.0
      GO TO 4
 92   IF(CVV-4.0)93,94,94
 93   M=2
      CVD=CVV-3.0
      GO TO 4
 94   IF(CVV-5.0)95,96,96
 95   M=3
      CVD=CVV-4.0
      GO TO 4
   96 M=4
      CVD=CVV-5.0
 4    IF(BH/3.0-1.0)7,8,8
 7    I=1
      GO TO 9
 8    I=2
 9    LL=100.0*CP
      ALL=LL
      AL=100.*CP-ALL
      IF(AL-.5)10,11,11
   10 J=LL-47
      GO TO 12
   11 J=LL-46
 12   K=20.*(VL+.05)-9.
      L=XPFF(I,J,K)
      L=L+1035*M
      AA=CR(L)
      L=XPPFF(I,J,K)
      L=L+1035*M
      BB=CR(L)
      L=XPFF(I+1,J,K)
      L=L+1035*M
      CC=CR(L)
      L=XPPFF(I+1,J,K)
      L=L+1035*M
      DD=CR(L)
```

```
      L=XPFF(I,J,K-1)
      L=L+1035*M
      EE=CR(L)
      L=XPPFF(I,J,K-1)
      L=L+1035*M
      FP=CR(L)
      L=XPFF(I+1,J,K-1)
      L=L+1035*M
      GG=CR(L)
      L=XPPFF(I+1,J,K-1)
      L=L+1035*M
      HH=CR(L)
      ABB=(BB-AA)*CVD+AA
      ACC=(DD-CC)*CVD+CC
      ADD=(FP-EE)*CVD+EE
      AEE=(HH-GG)*CVD+GG
      IF(BH-3.0)23,24,24
   23 BHD=BH-2.25
      GO TO 25
   24 BHD=BH-3.00
   25 BAA=(ACC-ABB)*BHD/0.75+ABB
      BBB=(AEE-ADD)*BHD/0.75+ADD
      AK=K
      VLR=0.45+AK*0.05
      VLD=VLR-VL
      CRINT=BAA-(BAA-BBB)*VLD/0.05
      ACRINT=CRINT/1000.
      RETURN
      END
```

```
      SUBROUTINE COST(WO,WS,SHP,WF,V,RA,PTB,FK10,FK5,DELPTB,DELDIS)
      PSP=(218.4-0.02138*WS+0.000002061*WS**2-0.0000000001149*WS**3)
      PSP=PSP*0.000004
      IF(WO-1400.)44,44,45
 44   PO  =(1100.0-0.043*WO+0.000112*WO**2-0.0000001323*WO**3)*WO*4.
      PO=PO*0.000001
      GO TO 49
45    IF (WO-2600.) 46,47,47
 46   PO  =(2430.0-1.928*WO+0.000722*WO**2-0.00000091*WO**3)*WO*4.
      PO=PO*0.000001
      GO TO 49
 47   PO  =698.8*WO*4.
      PO=PO*0.000001
49    IF (SHP-13000.) 55,55,58
 55   PM  =(137.7-(SHP/(75.32+0.00592*SHP)))*SHP*4.
      PM=PM*0.000001
      GO TO 59
 58   PM  =(SHP/(0.03249*SHP-173.95))*SHP*4.
      PM=PM*0.000001
   59 PF=FK10*FK5*WF*V/RA
      PF=PF*0.000001
      PBAL=0.001*DELDIS
      PTB=0.0704*(PO+PSP+PM+PBAL)+PF
      DELPTB=PTB
      RETURN
      END
```

```
      SUBROUTINE OUTPUT(DIS,CP,VL,CXAP,
     1FL,FLBP,B,D,H,CB,NCYCLE, CV,FLD,BH,CNT,NCRA,ROWSN,
     2FK1,SHP,ACT,ACRINT,CF,CS,WS,WO,WM,WF,RPLOAD,WMA,REQDIS,DELDIS
     3FAR,FA,DELFA,FKB,FKM,FKG,GM,GMBR,PTB,INDEX)
      DIMENSION TIME(4),XMIN(4),XMAX(4),CR(6210)
      COMMON TIME,M,MA,MB,MC,N,XMIN,XMAX,CR,
     1V,RA,WEC,CNT,CNV,CNA,CNLPH,CNVB,CLE,CBF,CHE,DBH,
     2CLEAR1,CLEAR2,CLEAR3,CLEAR4,CBC,FW,WTW,DT,HHC,TOL,CAMBER,HATC
     3FK,FK1,FK2,FK3,FK4,FK5,FK8,FK9,FK10,FK12
      K=2
      IF(INDEX)505,502,501
  501 WRITE OUTPUT TAPE K,1
    1 FORMAT(42H1FINAL RESULTS OF SHIP DESIGN OPTIMIZATION//)
      GO TO 222
  502 WRITE OUTPUT TAPE K,503
 503  FORMAT(21H INTERMEDIATE RESULTS//)
      GO TO 222
  505 WRITE OUTPUT TAPE K,506
 506  FORMAT(44H INITIAL DESIGN BASED ON RANDOM INPUT VALUES//)
  222 WRITE OUTPUT TAPE K,40,NCYCLE
   40 FORMAT(22H THIS IS LOOP NUMBER ,I4/)
      WRITE OUTPUT TAPE K,2
    2 FORMAT(20H 1. RANDOM VARIABLES)
      WRITE OUTPUT TAPE K,3,DIS,CP,VL,CXAP
    3 FORMAT(21H DISPLACEMENT (MLD.)=,1F8.1,5H TONS,5X,3HCP=,1F5.3,
     15X,10HV/SQRT(L)=,F5.3,5X,3HCX=,F5.3/)
      WRITE OUTPUT TAPE K,4
    4 FORMAT(19H 2. MAIN DIMENSIONS)
      WRITE OUTPUT TAPE K,5,FL,FLBP,B,D,H
    5 FORMAT(5H LWL=,F6.1,4H FT.,4X,4HLBP=,F6.1,4H FT.,4X,8HB(MLD.)
     1F6.2,4H FT.,4X,8HD(MLD.)=,F6.2,4H FT.,4X,8HH(MLD.)=,F6.2,4H F
      WRITE OUTPUT TAPE K,6
    6 FORMAT(21H 3. FORM COEFFICIENTS)
      WRITE OUTPUT TAPE K,7,CB,CP,CXAP,CV
    7 FORMAT(4H CB=,1F5.3,5X,3HCP=,1F5.3,5X,3HCX=,1F5.3,5X,3HCV=,1F
      WRITE OUTPUT TAPE K,8
 8    FORMAT(33H 4. RATIOS OF THE MAIN DIMENSIONS)
      BOD=B/D
      FLOB=FL*FK9/B
      HOD=H/D
      WRITE OUTPUT TAPE K,9,FLD,FLOB,BOD,HOD,BH
    9 FORMAT(7H LBP/D=,F6.3,4X,6HLBP/B=,F6.3,4X,4HB/D=,F5.3,4X,4HH/
     1F5.3,4X,4HB/H=,1F5.3/)
      WRITE OUTPUT TAPE K,20
   20 FORMAT(25H 5. CONTAINER ARRANGEMENT)
      CRA=NCRA
      WRITE OUTPUT TAPEK,21,CNT,ROWSN,CRA
   21 FORMAT(1H ,F6.1,27H CONTAINERS ARE CARRIED IN ,F4.1,5H ROWS/
     173H ACTUAL NUMBER OF CONTAINERS THAT COULD BE CARRIED IN AVAI
     2 SPACE IS ,F6.1/)
      WRITE OUTPUT TAPE K,10
   10 FORMAT(34H 6. RESISTANCE AND PROPULSION DATA)
      EHP=SHP/FK1
```

```
      SERSHP=SHP/1.25
      QPC=0.75
      WETSUR=CS*SQRTF(DIS*FL)
      WRITE OUTPUT TAPE K,11,SHP,SERSHP,EHP,QPC,ACT,ACKINT,CF,VL,WE
   11 FORMAT(16H MAXIMUM S.H.P.=,F7.1/
     116H 0.8MAX. S.H.P.=,F7.1/16H E.H.P.(TAYLOR)=,F7.1/
     25H QPC=,F5.3,5X,3HCT=,F6.4,5X,3HCR=,F6.4,5X,3HCF=,F6.4,5X,
     310HV/SQRT(L)=,F6.4/16H WETTED SURFACE=,F10.3,7H FT.SQ./)
      WRITE OUTPUT TAPE K,12,WS,WO,WM,WF,WMA,RPLOAD,DELDIS,DIS
   12 FORMAT(11H 7. WEIGHTS/
     134H STEEL WEIGHT                    = ,1F8.1,5H TONS/
     234H OUTFIT WEIGHT                   = ,1F8.1,5H TONS/
     334H MACHINERY WEIGHT                = ,1F8.1,5H TONS/
     434H FUEL WEIGHT                     = ,1F8.1,5H TONS/
     534H CREW AND EFFECTS                = ,1F8.1,5H TONS/
     634H REQUIRED PAYLOAD                = ,1F8.1,5H TONS/
     734H BALLAST WEIGHT                  = ,1F8.1,5H TONS/
     834H DISPLACEMENT                    = ,1F8.1,5H TONS/)
      WRITE OUTPUT TAPEK,14
   14 FORMAT(18H 8. FREEBOARD DATA)
      DEL =-DELFA
      WRITE OUTPUT TAPE K,16,FAR,FA,DEL
   16 FORMAT(21H AVAILABLE FREEBOARD=,F6.2,4H IN./
     121H REQUIRED  FREEBOARD=,F6.2,4H IN./
     221H EXCESS    FREEBOARD=,F6.2,4H IN./)
      FRESUR=0.0
      GMR=GMBR*B
      DELGM=GM-GMR
      WRITE OUTPUT TAPE K,13,FKB,FKM,FKG,FRESUR,GM,GMR,DELGM
   13 FORMAT(18H 9. STABILITY DATA/
     14H KB=,1F5.2,4H FT.,5X,3HKM=,1F5.2,4H FT.,5X,3HKG=,1F5.2,4H F
     25X,25HFREE SURFACE CORRECTION=-,1F5.2,4H FT.,/
     313H GM         =,F5.2,4H FT.,/
     413H GM REQUIRED=,F5.2,4H FT.,/
     513H EXCESS GM  =,F5.2,4H FT./)
      WRITE OUTPUT TAPE K,15,PTB
   15 FORMAT(21H 10. ECONOMIC RESULTS/
     143H EQUIVALENT YEARLY COST IN MILLION DOLLARS=,F10.6//)
      WRITE OUTPUT TAPE K,1000
 1000 FORMAT(1H1)
      RETURN
      END
```

APPENDIX II

A) Original Resistance Data Arrangement

The Taylor's Residual Resistance Coefficients (CRR) are input to the resistance subroutine and are given in the first 1035 data cards. The CRR's are given for three values of B/T starting at 2.25 and increasing with equal increments of 0.75 up to 3.75, for 23 values of C_p starting at 0.48 and increasing with equal increments of 0.01 up to 0.70, for 15 values of $V/\sqrt{L}$ starting at 0.50 and increasing with equal increments of 0.05 up to 1.20 and for 6 values of C_v starting at 0.001 and increasing with equal increments of 0.001 up to 0.006. The total number of CRR's is then 3 x 23 x 15 x 6 = 6210.

The CRR's are arranged in the following manner:

CRR(1) is the CRR for B/T = 2.25, C_p = 0.48, $V/\sqrt{L}$ = 0.50, C_v = 0.001

... ...

CRR(6) is the CRR for B/T = 2.25, C_p = 0.48, $V/\sqrt{L}$ = 0.50, C_v = 0.006

CRR(7) is the CRR for B/T = 2.25, C_p = 0.48, $V/\sqrt{L}$ = 0.55, C_v = 0.001

... ...

CRR(91) is the CRR for B/T = 2.25, C_p = 0.49, $V/\sqrt{L}$ = 0.50, C_v = 0.001

... ...

CRR(2071) is the CRR for B/T = 3.00, C_p = 0.48, $V/\sqrt{L}$ = 0.50, C_v = 0.001

... ...

CRR(6210) is the CRR for B/T = 3.75, C_p = 0.70, $V/\sqrt{L}$ = 1.20, C_v = 0.006

B) Resistance Data Rearrangement

It is found that if the Taylor's Resistance coefficients (CRR) are rearranged into a new array called CR, they are more expeditiously incorporated into the resistance subroutine as given in Appendix I. The CR's are arranged in the following manner:

CR(1) is the CR for B/T = 2.25, $C_p = 0.48$, $V/\sqrt{L} = 0.50$, $C_v = 0.001$

CR(2) is the CR for B/T = 2.25, $C_p = 0.48$, $V/\sqrt{L} = 0.55$, $C_v = 0.001$

....

CR(15) is the CR for B/T = 2.25, $C_p = 0.48$, $V/\sqrt{L} = 1.20$, $C_v = 0.001$

CR(16) is the CR for B/T = 2.25, $C_p = 0.49$, $V/\sqrt{L} = 0.50$, $C_v = 0.001$

....

CR(345) is the CR for B/T = 2.25, $C_p = 0.70$, $V/\sqrt{L} = 1.20$, $C_v = 0.001$

CR(346) is the CR for B/T = 3.00, $C_p = 0.48$, $V/\sqrt{L} = 0.50$, $C_v = 0.001$

CR(1036) is the CR for B/T = 2.25, $C_p = 0.48$, $V/\sqrt{L} = 0.50$, $C_v = 0.002$

....

CR(6210) is the CR for B/T = 3.75, $C_p = 0.70$, $V/\sqrt{L} = 1.20$, $C_v = 0.005$

C) Arrangement of Other Input Data

Other input data necessary for the algorithm of this report are arranged in six groups as follows:

1. Parameters controlling the exponential search.
   a) Percentage of the total number of loops that each value of the exponent of the exponential transformation function is to be used, (1/L).
   b) Values of the exponent of the exponential transformation function, (M).

c) Total number of sampling loops, (L).

d) Minimum, maximum and initial values of Δ, C_p, $V/\sqrt{L}$ and C_m.

2. Owner's specification

a) Service speed in knots, (V) and range in nautical miles, (E).

b) Maximum number of containers to be carried per voyage, (N).

c) Maximum weight of each container when fully loaded in long tons, (WEC).

3. Container dimensions

a) Container length in feet, (CL).

b) Container width in feet, (CW)

c) Container height in feet, (CH)

4. Container distribution

a) The number of container rows per hold, (NCRHL).

b) The number of containers per column, (NCC).

c) The number of containers per cell, below deck, (NCCBD).

d) The number of containers per row, (NCR).

5. Auxiliary data

a) K1 = SHP/EPH

K2 = KB/T

K3 = KG(steel)/D

K4 = KG(outfit)/D

K5 = Fuel cost in dollars

K8 = KG(stores)/D

K9 = LBP/LWL

K10 = ship use factor

5. Auxiliary data (cont).

$K12 = GM_r/B$

and shape coefficient

6. Clearances

a) Longitudinal clearance per hold in feet, (LCH) (depends on the number of container rows per hold).

b) Transverse clearances between containers in inches, (TCBC), flange width in feet, (FW) and total wing tank width in feet, (WTW).

c) Doubler thickness in inches (DT), vertical clearance inside the hold in inches, (TOL), camber in inches, (CA), hatch coaming height, in inches, (HCH), hatch cover height in inches, (HC) and double bottom height in inches, (DBH).