SSC-289

A METHOD FOR ECONOMIC TRADE-OFFS OF ALTERNATE SHIP STRUCTURAL MATERIALS

SHIP STRUCTURE COMMITTEE

1979

Member Agencies:
United States Coast Guard
Naval Sea Systems Command
Military Sealift Command
Maritime Administration
United States Geological Survey
American Bureau of Shipping

Ship Structure Committee

An Interagency Advisory Committee
Dedicated to Improving the Structure of Ships

Address Correspondence to:
Secretary, Ship Structure Committee
U.S. Coast Guard Headquarters, (G-M/82)
Washington, D.C. 20590

SR-1222

JULY 1979

In past years, the Ship Structure Committee has conducted several studies to determine the comparative effectiveness of glass-reinforced plastics and aluminum for ship hull construction. The procedure followed required that a fairly complete set of competitive ship designs be developed for each evaluation, making this type of trade-off investigation an expensive and time-consuming process.

To improve this situation, simpler, quicker and less expensive procedures, which would still yield the level of accuracy necessary to support investment in expensive material development projects and to justify construction of ships of uncommon material combinations, were sought. The initial approach has been to develop a model that examines the economic effects of such things as ship life, construction costs, repair and maintenance costs, together with noneconomic considerations, such as suitability for intended use, environmental impact and use of natural resources.

This report describes this effort and provides an example comparing aluminum and mild steel. Your comments and opinions on this report or on future studies are encouraged.

Henry H. Bell
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

SSC-289

FINAL REPORT

on

Project SR-1222

"Materials Trade-Off Study"

A METHOD FOR ECONOMIC TRADE-OFFS OF ALTERNATE SHIP STRUCTURAL MATERIALS

by

C. R. Jordan
R. P. Krumpen, Jr.
J. B. Montgomery, and
D. J. Wooley

Newport News Shipbuilding Co.

under

Department of the Navy
Naval Sea Systems Command
Contract No. N00024-77-C-5323

U. S. Coast Guard Headquarters
Washington, D.C.
1979

SHIP STRUCTURE COMMITTEE

The SHIP STRUCTURE COMMITTEE is constituted to prosecute a research program to improve the hull structures of ships and other marine structures by an extension of knowledge pertaining to design, materials and methods of construction.

RADM H. H. Bell (Chairman)
Chief, Office of Merchant Marine Safety
U. S. Coast Guard Headquarters

Mr. P. M. Palermo
Assistant for Structures
Naval Ship Engineering Center
Naval Sea Systems Command

Mr. W. N. Hannan
Vice President
American Bureau of Shipping

Mr. M. Pitkin
Assistant Administrator for Commercial Development
Maritime Administration

Mr. R. B. Krahl
Chief, Branch of Marine Oil and Gas Operations
U. S. Geological Survey

Mr. C. J. Whitestone
Chief Engineer
Military Sealift Command

LCDR T. H. Robinson, U. S. Coast Guard (Secretary)

SHIP STRUCTURE SUBCOMMITTEE

The SHIP STRUCTURE SUBCOMMITTEE acts for the Ship Structure Committee on technical matters by providing technical coordination for the determination of goals and objectives of the program, and by evaluating and interpreting the results in terms of structural design, construction and operation.

U. S. COAST GUARD

Cdr. J. C. Card
Lcdr S. H. Davis
Capt C. B. Glass
Dr. W. C. Dietz

NAVAL SEA SYSTEMS COMMAND

Mr. R. Chiu
Mr. R. Johnson
Mr. G. Sorkin
Mr. J. B. O'Brien (Contracts Admin.)

MARITIME ADMINISTRATION

Mr. F. J. Dashnaw
Mr. N. O. Hammer
Mr. F. Seibold
Mr. M. Touma

NATIONAL ACADEMY OF SCIENCES
SHIP RESEARCH COMMITTEE

Mr. O. H. Oakley - Liaison
Mr. R. W. Rumke - Liaison

SOCIETY OF NAVAL ARCHITECTS & MARINE ENGINEERS

Mr. A. B. Stavovy - Liaison

WELDING RESEARCH COUNCIL

Mr. K. H. Koopman - Liaison

MILITARY SEALIFT COMMAND

Mr. T. W. Chapman
Mr. A. B. Stavovy
Mr. D. Stein
Mr. J. Torresen

AMERICAN BUREAU OF SHIPPING

Dr. H. Y. Jan
Mr. D. Liu
Mr. I. L. Stern
Mr. S. G. Stiansen (Chairman)

U. S. GEOLOGICAL SURVEY

Mr. R. Giangerelli
Mr. J. Gregory

INTERNATIONAL SHIP STRUCTURES CONGRESS

Prof. J. H. Evans - Liaison

AMERICAN IRON & STEEL INSTITUTE

Mr. R. H. Sterne - Liaison

STATE UNIV. OF NEW YORK MARITIME COLLEGE

Dr. W. R. Porter - Liaison

U. S. COAST GUARD ACADEMY

Capt W. C. Nolan - Liaison

U. S. NAVAL ACADEMY

Dr. R. Battacharyya - Liaison

U. S. MERCHANT MARINE ACADEMY
Dr. Chin-Bea Kim - Liaison

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION / 2b. GROUP
Newport News Shipbuilding Newport News, Virginia	Unclassified / N/A

3. REPORT TITLE

A METHOD FOR ECONOMIC TRADE-OFFS OF ALTERNATE SHIP STRUCTURAL MATERIALS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report

5. AUTHOR(S) (First name, middle initial, last name)

C. R. Jordan
James B. Montgomery
R. P. Krumpen, Jr.
D. J. Wooley

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 30, 1978	135	26

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
N00024-77-C-5323	Job Order 2011T
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	N/A

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
N/A	Naval Sea Systems Command

13. ABSTRACT

A method for evaluating the desirability of any proposed material in merchant ship structure has been developed. This method compares a ship designed of the new material with a similar steel ship. Comparison includes a life-cycle cost analysis and a quantified evaluation of non-economic factors. Formalized techniques for establishing the material data bank, selecting the steel ship design, developing and optimizing the new material design, and conducting the economic and non-economic comparisons are described. A sample calculation, using 5456 aluminum in a bulk ore carrier, is included to illustrate the method.

KEY WORDS

Ship structural material
Economic analysis
Non-economic evaluation
ABS steel material properties
5456 aluminum material properties
Structural synthesis
Ship optimization

DD FORM 1 NOV 65 1473 (PAGE 1)
S/N 0101-807-6801

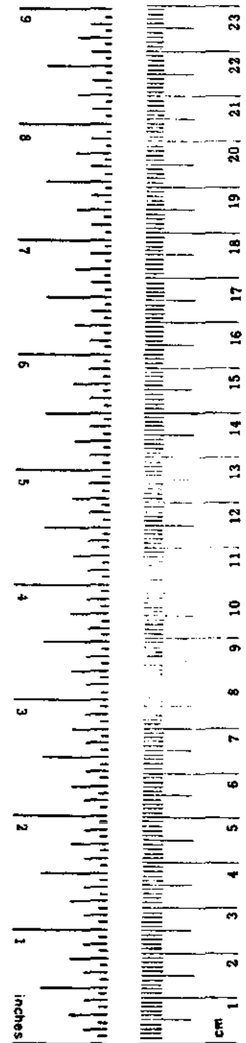
UNCLASSIFIED
Security Classification

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

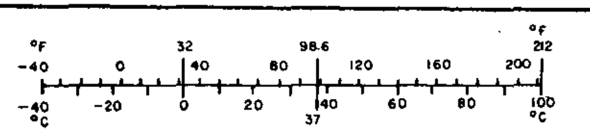
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	
cm	centimeters	0.4	inches	
m	meters	3.3	feet	
m	meters	1.1	yards	
km	kilometers	0.6	miles	
		AREA		
cm^2	square centimeters	0.16	square inches	
m^2	square meters	1.2	square yards	
km^2	square kilometers	0.4	square miles	
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	
kg	kilograms	2.2	pounds	
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	
l	liters	2.1	pints	
l	liters	1.06	quarts	
l	liters	0.26	gallons	
m^3	cubic meters	35	cubic feet	
m^3	cubic meters	1.3	cubic yards	
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	



CONTENTS

CONTENTS (Cont'd)

Page

Appendices

LIST OF FIGURES

LIST OF FIGURES (CONT.)

INTRODUCTION

Work under this contract was limited to the development of a method for conducting Material Trade-Off Studies for merchant ships, and to the performance of a sample calculation to demonstrate that method. The contract did not include the development of a method applicable to non-merchant vessels, or the development of computer programs to perform the calculations, or the preparation of data needed for the sample calculation. Valid data were to be used when available; where such data could not be obtained, reasonable estimates were to be used to illustrate the application of the method.

The purpose of a Material Trade-Off Study is to evaluate the desirability of a proposed new material for merchant ship structure. Implicit in the term "Trade-Off Study" is the requirement that there be at least two alternates to be compared. For Material Trade-Off Studies, the alternate material used for comparison is steel. Steel was selected because of its use and acceptability throughout the shipbuilding industry.

The method developed during this project provides a rational and systematic way to compare a ship built of any proposed new material with a similar ship built of steel. This approach is intended to meet the needs of a shipowner who wants to investigate the use of an alternate structural material for a specific ship design. It is, however, a very flexible method and is equally well suited to the needs of a material supplier who wants to find new applications for his product, or to the needs of a researcher who wants to improve existing materials or develop new ones. The method can be used to evaluate the desirability of an alternate material for an entire ship structure, or for any selected part of that structure (such as cargo holds or bottom shell); it thus permits the consideration of different materials in different parts of the ship. It can also be used to evaluate the effect of proposed changes in material properties, and thus to indicate the desirability of proposed research and development of improved materials. The method is well adapted to computer operation and can be used for parametric studies as well as for investigations of single ship designs.

CONCLUSIONS

Work performed during this study has produced a viable method for evaluating the use of a proposed new material in the structure of merchant vessels. The method is based on comparison of a ship built of the new material with a similar steel ship. It includes systematic techniques for substituting the new structural material in place of steel, for "optimizing" the resulting new ship, for developing the construction costs of that optimized ship, and for evaluating the worth of the new ship compared to the original steel ship.

Caution must be used in interpreting the results of any Material Trade-Off Study using this method. The results of such a study apply only to the particular circumstances investigated (the specific ship, cargo, owner and trade route) and do not necessarily apply in other cases. It is not safe, therefore, to draw general conclusions about a material from the results of one or only a few studies.

There are many reasons why Material Trade-Off Studies of the same material may produce apparently conflicting answers in different circumstances. One reason is that the material may not be equally well suited to all applications. An obvious example is that a material which is "very advantageous" in one trade would be "undesirable" in another trade if it were incompatible with the cargo carried in the second trade. A less obvious example is that a material with a relatively high acquisition cost might be "undesirable" in a trade where the ratio of annual capital amortization cost to annual operating cost was high, but "advantageous" when this ratio was reversed. This means that a study involving the same ship and cargo could produce different results on different trade routes.

A second reason for the variation in results under different circumstances is the different requirements of different owners. As noted in the section "EVALUATION OF ECONOMIC FACTORS", many of the economic parameters used in the calculation of RFR are established by the specific owner. Changes in these requirements are reflected by differences in RFR and, therefore, by changes in final material worth.

A more significant source of variation in material assessment is in the choice of non-economic "factors" and "attributes"; the assignment of "values" and "weights" for each attribute, as discussed in the section "EVALUATION OF NON-ECONOMIC FACTORS"; and the assignment of the (dollar per ton) multipliers used to convert "factor ratings" to "factor worths", as discussed in the section "COMBINED EVALUATION". All of these parameters are selected subjectively by the owner or analyst. No two analysts would make the same selections, so no two analysts would produce the same results.

The apparent lack of repeatability of calculations performed with this method is not a defect of the system. Instead it reflects the basic fact that the same material will not be equally good for all applications. The surprising thing is that the term "different applications" includes such apparently minor variations as the same ship for different trade routes, or the same ship and trade route for different owners. It would, of course, be possible to make a rigid definition of all the parameters that are used in the analysis and thus ensure repeatability of results. This approach was not used and is not recommended because it would generalize the procedure to a point where it was academically interesting but of no value for practical use.

A sample calculation is included in the report to illustrate the steps to be followed in a Material Trade-Off Study. This calculation evaluated the use of 5456 aluminum for the hull structure of a bulk carrier transporting ore from Seattle to Yokohama. Evaluation was performed from the point of view of a (hypothetical) ship owner. If a different viewpoint were used, some of the evaluation criteria would change and the results might be different.

Three aluminum ship configurations were developed. One had the same geometry as the steel ship (with greater cargo capacity), one had the same cargo capacity (with a different ship size), and the third had the cargo capacity (and ship size) increased to reduce RFR. Results of the study are:

SHIP TYPE	EVALUATION	WORTH OF ALUMINUM
same geometry	pessimistic	- 0.41 $/ton
	most probable	- 0.32
	optimistic	- 0.22
same cargo capacity	pessimistic	- 0.69
	most probable	- 0.60
	optimistic	- 0.51
increased cargo capacity	pessimistic	- 0.21
	most probable	- 0.11
	optimistic	- 0.02

Negative worths mean that aluminum is less desirable than steel. These worths can be compared directly with the steel ship RFR of 9.44 $/ton to assess the importance of the numbers. On the basis of the sample study, aluminum would not be recommended for the needs of this owner.

METHOD

Evaluation of the desirability of a proposed new material for merchant ship hull structure can be done in a straightforward manner as shown in Figure 1. A steel ship is selected to serve as the standard against which the new ship can be compared, a ship using the new material is designed, and the advantages and disadvantages of the two ships are quantified. For merchant ships, the primary attribute to be measured is profitability. This is frequently expressed in terms of Required Freight Rate (RFR), so RFR is used as the measure of merit in this study. Non-economic factors are expressed as an equivalent percentage of this value and combined with it. The resulting numerical rating is a measure of the worth of the new material in the specific circumstances studied. This evaluation process involves six steps.

The first step is to select a steel ship on which to base the trade-off study. It may be an existing ship or a proposed new design. When the study is being performed for a specific owner, cargo and trade route, this selection is simple; but when the study is intended to provide general information about a proposed material, the selection is more complex. The apparent worth of a new material is affected by the type of steel ship with which it is compared. For example: a material which reduces structural weight may be very advantageous for carrying a dense cargo such as iron ore but may be of no value for a light cargo. A material with high resistance to fouling and corrosion but poor cold weather properties may be very advantageous in the tropics but unsuitable for operation in Arctic ice. It is important to remember that the results of an evaluation under one set of conditions cannot be applied to other sets of conditions without careful reanalysis.

When the cargo and trade route have been established, the characteristics of the specific steel ship can be selected. This ship will serve two purposes. First, it will serve as the "parent" for design of a comparable and similar ship of the new material. Second, it will serve as a "base" for quantification of the superiority or inferiority of the new material under the specified circumstances.

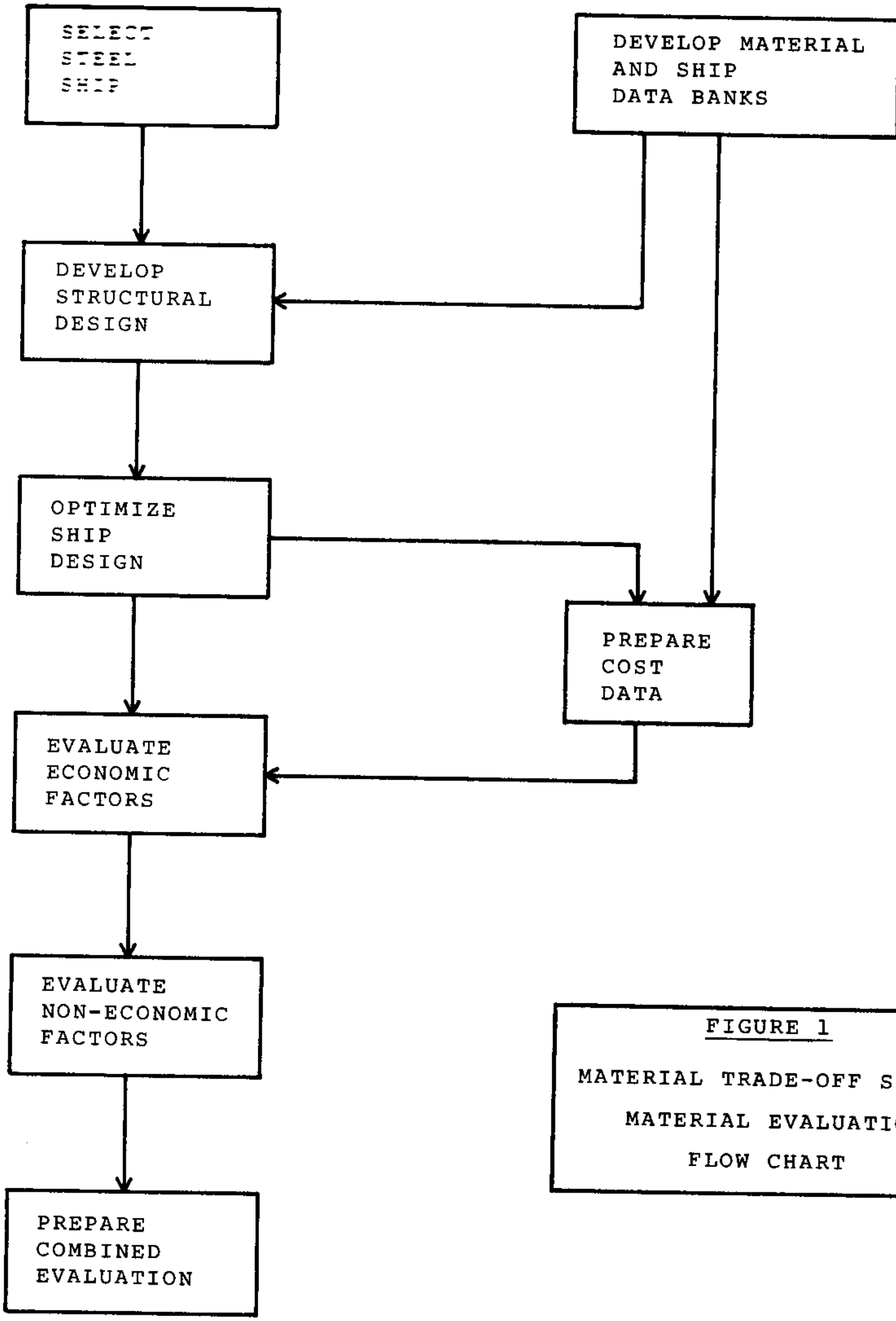


FIGURE 1

MATERIAL TRADE-OFF STUDY

MATERIAL EVALUATION

FLOW CHART

The second step is to develop a ship structural design using the new material. This new design is based on the ship selected in Step One, using the same ship lines, powering, and general arrangement. The new structure can be designed by any standard Naval Architectural methods, or it can be adapted from the steel ship structure as described in the section "STRUCTURAL DESIGN DEVELOPMENT". The latter method is recommended when several ship designs or materials are involved because it is quicker and less expensive, and because it produces consistent results when many comparisons are to be made.

The third step is to "optimize" the new design. This process involves modifications to the "new ship" design to improve its worth to the shipowner. These modifications may include changes to things such as principal characteristics, cargo capacity, speed and power, and even to the type of machinery if the changed power permits, but they should not include changes to things such as cargo handling apparatus, outfitting, etc. Normally, the steel ship design should not be modified, but in some cases it may be necessary to optimize that design also to ensure a fair comparison between materials.

The optimization process can be done intuitively by any good Naval Architect, or it can be systematized and programmed for computer operation. Development of such a program was excluded from the scope of this contract and no complete program is currently available. A preliminary version of such a program is described in the section "DESIGN OPTIMIZATION".

The fourth step is to quantify the success with which the new ship fulfills its mission, as compared with the parent steel ship. The mission of a merchant ship is to earn money, so the measure of merit used for this analysis is Required Freight Rate (RFR). RFR's are calculated for each ship; the difference between them expresses numerically the economic advantage or disadvantage of the new material for the specified service. Any standard method can be used for calculating RFR; Appendix A describes a generalized computer program which is suitable for merchant ship applications. This program, or any other program, requires the ship construction cost as part of the input data.

Construction costs of the steel ship are included in the design information collected for that ship. Construction costs for the new ship can be estimated by normal cost estimating techniques, or can be extrapolated from the steel ship data as discussed in the section "EVALUATION OF ECONOMIC FACTORS". The latter technique can be systematized and combined with the computer program recommended in Step Three.

The fifth step is to evaluate the effect of non-economic factors on the desirability of the new material. Normally for a merchant ship, economics are all-important. However other factors should also be considered; in cases where the economic differences are small, these other factors may govern. For example, consider Risk. If an exotic material is used which can be welded at only one or two building yards, the ship operator faces the risk that the ship will be damaged while it is far from those yards and will be out of service until it is towed to one of them for repair. Such a risk cannot be measured economically but might negate a small advantage in RFR.

The section "EVALUATION OF NON-ECONOMIC FACTORS" describes how these factors can be analyzed. The analysis method is applicable to any non-economic factors. Five such factors have been described in the present study. These can be deleted, or replaced, or supplemented by other factors to suit the needs of any particular owner, without affecting the method of the Material Trade-Off.

The sixth step is to combine the results of the non-economic factor evaluation with the RFR advantage or disadvantage of the new material. The resulting number is a quantified measure of the worth of the new material for the selected application. The method for obtaining this final number is discussed in the section "COMBINED EVALUATION".

STEEL SHIP SELECTION

Almost any steel ship can be used as the base ship, but there should be a reasonable amount of information available to the analyst. He will need such data as ship operation and construction costs, geometry, weights, speed, horsepower and crew size. Information that is not available must be estimated, so the amount and accuracy of the available data directly affects the quality of the analysis.

The selected ship's cargo, trade route, and general characteristics also affect the evaluation. A new material being investigated will not be equally suited to all cargoes and trade routes. For example, a lightweight material might be advantageous where the steel ship was weight limited, but might offer no advantage if the ship were volume limited. When an analysis is undertaken for a specific owner, that owner will specify the service to be investigated. If, however, general information is needed on the performance of a proposed new material, the choice of service is more difficult. In this case, it may be necessary to perform a series of trade-off studies, using various types of steel ships, to be able to draw general conclusions as to the usefulness of the new material.

Once the ship type, cargo, and trade route have been established, a steel ship representative of that service can be chosen. As this steel ship will be used both as a base for developing the new material ship and as a standard of comparison for that vessel, it must be chosen carefully. It should be a successful, modern design which would be suitable for any new construction program.

STRUCTURAL DESIGN DEVELOPMENT

General Description

The structural development section of the evaluation process produces a "new" vessel which has the same lines and arrangement as the selected steel vessel. The only difference between the two ships is that the proposed new material is used for main hull structure in place of steel. This new structural design may be prepared by standard Naval Architectural calculations, or it may be synthesized from the steel structure as described below. The level of detail of the new structural design should be approximately that produced in a normal preliminary design study.

Structural Synthesis

Structure of the steel ship is broken down into "components" such as panels of stiffened plating, or pillars. An "equivalent" component of the new material is developed for each of these. (The term "equivalent component" means one which satisfies whatever structural requirements are applicable to it equally as well as the steel component it replaces.) The new components are reassembled into a new hull structure, and the new structure checked both for compatibility between its parts and for overall strength.

The magnitudes of the loads on each component are not calculated, but the type of loading is. "Equivalence" between a new material and steel for each component may be different for different loading conditions (tension, shear, combined, etc.), so that the new component scantlings depend on the type of load the component carries. If the steel component is adequate for the imposed load, any "equivalent" new material component will also be adequate for that load, so it is not necessary to calculate the magnitudes of the loads.

"Equivalence" depends not only on the type of loading but also on the function of the component. Structures, such as a watertight bulkhead, which is loaded only in an emergency and then is stressed beyond yield, may require different equivalencies from structure, such as a deep tank bulkhead, which is loaded frequently and whose design stresses are well below yield. If the mechanical properties, such as the stress-strain curve, of the new material are different from those of steel, the equivalency at working stresses may be very different from the equivalencies at yield, ultimate or fatigue stresses. Also, configurations with equal strength frequently produce widely different deflections and deflection may be the controlling factor. All of these possibilities must be considered in substituting new components for steel.

Selection of Existing Structural Components

The main hull structure of the steel ship is broken down into major segments, such as transverse bulkheads, longitudinal bulkheads, side shell, decks, etc. These segments are in turn broken down into components which can be handled by substitution. The basic components to be considered are:

1. Struts or Columns
2. Stiffened or Unstiffened Plates
3. Beams or Girders

Any structure which does not fall in one of these three categories is treated on a case basis.

Struts or columns are usually long slender members designed to carry an axial compressive load, but many variations of geometry and loading can be found in normal ship structure.

Plates are usually flat and rectangular. They may carry in-plane tensile, compressive or shear loads as well as normal loads.

Beams, such as transverse webs, girders and side shell longitudinals, are usually sections that provide edge support to plating panels. They are primarily loaded in bending, but tensile and compressive loads may be significant.

Development of Loading Characteristics

Each major hull segment has a structural function. The steel components of each segment have been designed for the type and magnitude of load, or combination of loads, generated by that function. The alternate material components are made equivalent in "resistance" to the steel components; they are, therefore, suitable for the loading to which they are exposed.

Types of loading to be considered are:

1. In-plane tension

2. In-plane compression

3. In-plane shear

4. Normal loads

Types of resistance to be considered are:

1. Equal "ultimate" load-carrying capacity

2. Equal "yield" or "buckling" load-carrying capacity

3. Equal "working" load-carrying capacity

4. Equal deflection under working loads

5. Equal deflection under design loads

6. Equal fatigue life under the type of loading expected

The required scantlings for an alternate material component are usually different for different combinations of "loading" and "resistance". In cases where the component design is governed by a single type of load, and other loadings are incidental, the corresponding equivalence formulas can be used directly. An example of this would be an oiltight flat which is also subjected to minor shear loadings from ship tension.

In cases where the component serves several major structural functions, new scantlings must be calculated for each load-resistance combination and the "worst case" solution used. An example of this would be a longitudinal oiltight bulkhead which forms part of the main hull girder. For some materials, the oiltight function of the bulkhead would govern the scantlings; for other materials, the main hull girder function would govern. All such functions must be checked.

A major part of any material trade-off study is developing the necessary formulas, or graphs to establish the scantlings of alternate material components. This is discussed below in the section "DATA BANK". The steel ship must be subdivided into components whose geometry and loading requirements are compatible with the formulas available in that data bank.

Selection of Alternate Material Structural Components

Using the formulas or the tables and graphs from the data bank, a new material component can be selected for each of the steel structural components. Several alternate components may be available from the data bank; in this case the following selection criteria is used.

1. Reject any component that is not suitable for all the types of loads that it may carry.

2. Reject any component which encroaches on space that is essential for some other purpose (e.g. a stiffener size that encroaches on space needed for stowing or moving containers).

3. Where deadweight is the controlling factor on cargo carrying capacity, trade-off structural weight versus initial cost to maximize life-cycle productivity.

4. Where volume is the controlling factor on cargo-carrying capacity, trade-off structural volume versus initial cost to maximize life-cycle producitivity.

Development of the New Material Structural Configuration

A total ship structural configuration suitable for preliminary design work is synthesized from the selected new material components. When this has been done, the overall structural design is checked to ensure compatibility between its various components. Each intersection is reviewed to ensure continuity of structure and to eliminate any interferences which may occur between adjacent members.

Longitudinal strength is checked by calculating a minimum required hull girder section modulus, using the base steel ship's hull girder section modulus and the appropriate stiffener equivalency formula from the data bank. The new material hull girder section modulus is then calculated and compared with the required minimum.

DESIGN OPTIMIZATION

All ship designs are not of equal quality. If several Naval Architects were to produce designs meeting identical requirements, those designs would differ. Necessarily, one of them would be "best" and one would be "worst". When only a single design is prepared, it is sometimes difficult to determine whether it is good, bad, or average. The steel ship selected as the "base" for developing the new material ship should be a good design, one which has been optimized for its service.

If the new material design has been developed by conventional Naval Architectural methods and, therefore, optimized to the same standards as the steel ship, no further optimization is required. However, if the new structural design was developed from old components by synthesis, optimization may be needed.

The process of changing steel structure to a different material can affect the quality of the design. Sometimes these differences are minor and easily overlooked; sometimes they are major. For example, consider a container ship. If the new structure encroaches on space needed for one row of containers, the reduction in the number of containers is very obvious. If, however, the new structure provides extra clearance around the containers, the difference might not be apparent but the new ship would be larger and more costly than necessary. In this example, the changes degraded the design; in other cases, the changes, may improve it.

Direct comparison of the new design with the steel design may be misleading. If, for example, a "poor" new design is compared with a "good" steel design, the apparent advantage of one material over the other may be caused by differences in design quality rather than by differences in material. The new design, then, must be optimized to the same criteria and level of excellence as the steel design. In some cases, it may be necessary to make changes to things such as hull form because of the new material, but changes of that type are undesirable.

In the case of a container ship, this modification is straightforward. The new ship must be expanded or contracted to fit the space required for containers. In other cases the choice is not so easy. If, for example, the new ship can carry more cargo than the steel ship when the hull and machinery characteristics are identical, there are three options:

1. Keep the hull and machinery characteristics identical and accept the greater cargo capacity;

2. Reduce the size of the ship and its machinery to make the cargo capacity the same as that of the steel ship; or,

3. Increase the size of the ship and its machinery to minimize RFR.

Although Option Three appears to be the best choice, it is not recommended. Normally RFR decreases with increasing ship size. It continues to decrease until the ship becomes so large that additional propellers or additional crew are required. If the new ship is arbitrarily made larger to reduce its RFR, it may make the new material appear superior to steel even though the superiority is solely due to the economies of increased size. If this option were to be followed, the steel ship should also be made larger to permit a fair comparison of the material worth. Changing both designs introduces complications and potential errors and is, therefore, not recommended. This objection is illustrated in Appendix G.

The choice between Options One and Two is less clear, but it can have a major impact on the results of any Material Trade-Off Study. When the new material produces a lighter structure than steel, Option One will usually provide a lower "new ship" RFR than Option Two. Conversely, if the new structure is heavier than steel, Option One will usually provide a higher RFR. There are no technical grounds for choosing one option over the other; the choice is a matter of opinion as to which option produces a more nearly "comparable" design. Option One is recommended because it is simpler to use and because it eliminates any problems of excessive beam, draft, powering, etc.

Regardless of which option is selected, the design may need to be modified (as in the example of the container ship) to meet specific cargo requirements. If Option One is used, these are the only changes to be made. If Option Two is used, the ship size and power must also be modified to make the cargo capacity the same as the steel ship. If Option Three is used, the ship size and power must be modified to "optimize" its performance with respect to RFR. In every case where ship dimensions have changed, the new dimensions must be checked to be sure they do not exceed any limitations on beam, draft, length, horsepower per shaft, etc.

Modifications to the ship design must be made in a systematic and repeatable fashion to permit consistent and reliable comparisons between the modified ship and the steel ship. Reference (1) describes a rational method for making these changes. This is further developed in the paragraphs below.

Method for Optimizing the Ship Design

A full description of the design to be optimized must be available, including:

principal dimensions	=	L,B,T
speed	=	V
power	=	SHP
weights - structure	=	W_s
- machinery	=	W_m
- outfit	=	W_o
- stores and supplies	=	W_{ss}
- personnel	=	W_p
- potable water	=	W_{pw}
- reserve feed water	=	W_r
- ballast	=	W_b
- fuel	=	W_f
- cargo	=	W_c

displacement = Δ = sum of these weights

Some of the weights (structure, outfit, ballast) are proportional to displacement; some of the weights (machinery, reserve feed water, fuel) are proportional to horsepower; some of the weights (stores and supplies, personnel, potable water) do not vary with minor changes in ship size; one of the weights (cargo) is independent of ship size.

Horsepower can be calculated by the Admiralty Coefficient method, providing the changes in ship size and speed are not excessive:

$$SHP = \frac{\Delta^{2/3} \quad V^3}{K}$$

where,

SHP = shaft horsepower

Δ = displacement

V = speed

K = Admiralty Coefficient

Horsepower, then, is proportional to the two-thirds power of displacement, and those weights which are proportional to horsepower also vary as $\Delta^{2/3}$.

The modified displacement can be found from the formula:

$$\Delta = k_s \Delta + k_m \Delta^{2/3} + k_o \Delta + W_{ss} + W_p + W_{pw} + k_r \Delta^{2/3} + k_b \Delta + k_f \Delta^{2/3} + W_c$$

where,

Δ = modified displacement

k_s = ratio of old W_s to old Δ

k_m = ratio of old W_m to old $\Delta^{2/3}$

k_o = ratio of old W_o to old Δ

k_r = ratio of old W_r to old $\Delta^{2/3}$

k_b = ratio of old W_b to old Δ

k_f = ratio of old W_f to old $\Delta^{2/3}$

This is a cubic equation which can be solved directly for the modified displacement. Horsepower is then calculated using the old ship Admiralty Coefficient, and ship dimensions are varied in the ratio of the cube roots of the displacements.

The modified ship design must be checked to ensure that any limitations on length, draft, beam or cargo-hold dimensions are not exceeded and to ensure that the horsepower per shaft has not become excessive. This process can be iterated, with any desired changes in principal dimensions, speed, power, or weights, until the design has reached an "optimum" based on any specified measure of excellence. The optimized ship design is then used for comparison with the steel ship.

Computer Program

The design optimization procedure described above is well suited for computer programming. Complete development of such program was specifically excluded from the scope of this contract, but a Program Flow Chart, Figure 2,

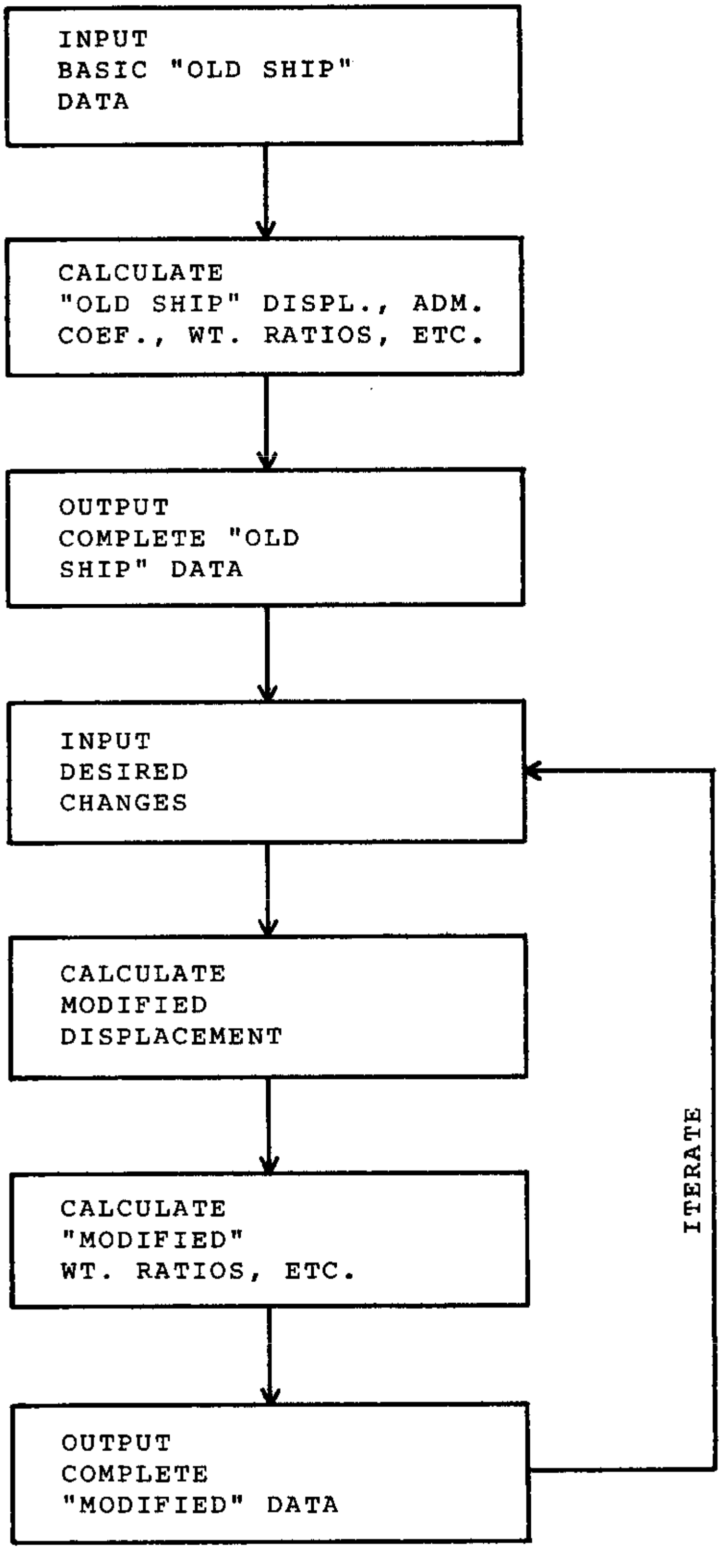


FIGURE 2

MATERIAL TRADE-OFF STUDY

SHIP OPTIMIZATION

FLOW CHART

has been prepared. In addition, a preliminary, simplified program was written to verify the processes of the flow chart. This preliminary program was used to develop the analyses shown in Appendix F.

EVALUATION OF ECONOMIC FACTORS

The purpose of a merchant ship is to make money. The worth of any change in structural material must, therefore, be measured by the effect of that change on the earning capacity of the ship. All other considerations are secondary.

A widely used measure of earning capacity is the Required Freight Rate (RFR). This Measure of Merit has been selected for use in the Material Trade-Off Study. It is defined as the freight rate, expressed in dollars per ton, which must be obtained to meet all expenses, both operating and amortization of investment, and to produce a specified return on investment. RFR's for the steel ship and for the new ship are calculated independently; the difference between these values is a single number which expresses the economic superiority or inferiority of the new ship.

Required Freight Rate

Any economic analysis that computes RFR can be used. Reference 26 and its references describe several of these. Others are used throughout the industry. It is essential that the same analysis method be used for both the steel ship and the new ship because different methods will produce different results. Appendix A describes a computer program which uses the Discounted Cash Flow method to calculate RFR. It was used in the sample Material Trade-Off Study of this report.

The steel ship RFR is used as a basis for determining the importance of the final worth evaluation of a selected material. A "new material" worth of $0.30/ton might be considered insignificant if the total RFR were $40/ton but could be very significant if the total RFR were <$1/ton). All data, which would affect RFR, must, therefore, be included in the economic analysis; it is not sufficient to analyze only those data which are affected by the difference in material.

The RFR calculation is based on a complete analysis of the ship, the trade route, the costs of acquiring and operating that ship, and the financial requirements of the prospective owner. Some of the input required for this analysis (things such as the ship type and trade route) is established at the start of each Material Trade-Off Study. Some of the input (things such as ship speed and cargo capacity) is established during the ship optimization. Some of the input (things such as costs and financial requirements) must be established as part of the economic analysis.

Operating costs and the financial requirements of a prospective owner can be developed from information supplied by that owner, or from published information on similar ships. Acquisition cost, however, must be developed by the analyst himself.

Acquisition Cost Estimate

Construction costs for both the steel ship and the new ship can be developed by standard shipyard cost-estimating procedures. This, however, is costly and time-consuming. A simpler method is needed, particularly when the study involves more than one new ship. Such a method is described below.

The total cost of ship acquisition can be subdivided into cost classes corresponding to the weight groups used for the weight calculation discussed in the section "DESIGN OPTIMIZATION", plus a separate class for "Administration" to cover such things as design costs, insurance, owners representatives, etc. Each cost class (except "Administration") can then be defined by cost factors (dollars per ton). "Administration" costs can be expressed as a percentage of the total. The acquisition cost for any ship design can be developed from these cost factors.

Cost factors for the steel ship can be calculated from actual cost data (or cost estimates) for the specific steel ship selected, or generalized cost factors based on industry-wide averages can be used. Cost factors for the new ship will be approximately the same as those of the steel ship for all classes except "Structure". A structural cost factor must be developed for each new material, based on cost estimates for typical construction. All these cost factors will be prepared in the early part of any Material Trade-Off Study and will form part of the data bank described in the section "MATERIAL DATA BANK".

Estimating costs by use of cost factors related to weight is not as accurate as the standard complete shipyard cost estimate. It is, however, sufficiently accurate for a Material Trade-Off Study because most of the weight groups, and the related costs, do not change appreciably between the designs to be compared. The major cost change is in "Structure". The cost factor for this class can, if desired, be further subdivided into cost factors for each of the types of structure included in the data bank. The structural cost can then be developed piecemeal as the structure itself is developed, in accordance with the method described in the section "STRUCTURAL DESIGN DEVELOPMENT".

The cost factor method permits rapid cost estimating and, more importantly, provides consistent results when several designs are involved. It also has the advantage that it can easily be programmed for computer application. Such a program could be included as part of the "optimization" program proposed in the section "DESIGN OPTIMIZATION" so as to calculate ship costs at the same time as ship designs.

EVALUATION OF NON-ECONOMIC FACTORS

Non-economic considerations are always less important than economic considerations in evaluating the worth of a merchant ship. Non-economic factors must, however, be considered in any complete evaluation. Many such factors have an effect on the owner's expectation of profit, even though that effect cannot be expressed in dollars. For example, the appearance of the ship may improve or degrade the reputation of the company in the eyes of the public and the financial institutions, and thus affect the availability of funds; or the risks associated with a particular material may increase or decrease the likelihood of unpredictable costs during the life of the ship.

The effects of these non-economic factors are usually significant only when the difference in RFR is small, but in some cases they may change the result from "favorable" to "unfavorable" or vice versa. The present study has developed a method for measuring these effects systematically and then combining them with the results of the economic analysis to obtain a single numerical measure of worth.

Method

The method is necessarily subjective rather than objective. No two owners will agree on the importance to them of all of the non-economic factors that may be considered, so the method must permit each owner to tailor the analysis to suit his needs. Appendix B shows the forms developed for this analysis.

The first step is to establish what non-economic factors are to be considered. Appendix B includes five typical factors:

Suitability for Intended Use

Environmental Impact

Use of National Resources

Government Involvement

Risk

Some of these factors will be more important to one owner than to another. Any particular owner may elect to eliminate some of them or to add others to suit his needs.

Each factor is subdivided into "attributes" which describe the important aspects of that factor. In this case also, any particular owner may elect to eliminate some of the attributes or to add others to suit his needs. Each attribute is assigned a "weight" which indicates its importance relative to other attributes of the same factor. The most important attribute is assigned a weight of 10. Other attributes are assigned weights which indicate their importance relative to the "most important" attribute and to each other. The relative importances must be established by the person performing each Material Trade-Off Study; they will be different for different studies because they must be adapted to each owner's needs. For this reason, values are not shown for the attribute weights in Appendix B. Typical values are used in the Sample Calculation of Appendix H.

After all the factors, attributes and attribute weights have been established for a particular Material Trade-Off Study, a "value" can be assigned to each attribute. Again, this assignment is subjective. It reflects the evaluator's opinion as to the significance of the difference imposed on that attribute by the change in structural material. Attribute values are assigned on a scale of 0 to +10 when the selected material is superior to steel and 0 to -10 when it is inferior. In either case, a value of 0 indicates that the change in material has no measurable effect on that attribute; a value of 10 indicates that the effect is major. Because of the difficulty in establishing authoritative numbers for these "values", three numbers are assigned: "pessimistic", "most probable", and "optimistic". This produces three "factor ratings" which are then used to calculate three "total worths" of the material.

After all the attribute values for a particular factor have been assigned, the values can be multiplied by the related weights and the "weighted averages" calculated. The weighted averages are divided by 10 to normalize them within the range -1 to +1, and the resulting numbers used for the "factor rating".

The normalized ratings for different factors are independent of each other and of the RFR value, so they must all be combined to establish the total worth of the material. A method for combining them is described in the section "COMBINED EVALUATION".

COMBINED EVALUATION

The economic evaluation produces a Required Freight Rate (RFR) expressed in dollars per ton. The non-economic evaluation produces pure numbers. These two evaluations must be combined to develop the total worth of the proposed ship. Figure 3 shows how this is done, using the five non-economic factors described in Appendix B as an example.

Profitability is the most important consideration in assessing the worth of a merchant ship. Total worth is, therefore, expressed in economic terms - dollars per ton. As the steel ship and the new ship RFR's are already in those units, worth of the economic factor can be taken as the difference between the two RFR's. However, "factor ratings" of non-economic factors must be converted to those units. Each non-economic factor rating is, therefore, multiplied by a dollar/ton value to obtain its "worth". These multipliers must be established by the analyst, based on the importance of each factor to his operations or on his evaluation of industry experience. He should consider both the actual cost ("This factor is worth x $/ton to me.") and its relationship to the base ship RFR ("This factor is worth Y% of the base ship RFR to me.").

The sum of the individual worths of the non-economic factors, plus the worth of the economic factor, gives the total worth of the new ship. These three values (pessimistic, most probable, and optimistic), are a measure of the advantage or disadvantage the new material offers when compared with steel. Their significance depends not only on the calculated worth of the new material but also on the RFR of the steel ship with which they are compared. As mentioned earlier, a "new material worth" of $0.30/ton is much more valuable when the steel ship RFR is < $1.00/ton than it is when the RFR is $40.00/ton.

The multiplying ($/ton) values used to convert factor ratings to factor worths are not shown in Figure 3. They must be established during each Material Trade-Off Study. Partly, this is so that the relationship between the worths of the various factors will reflect the needs of the specific owner involved, and partly, it is to ensure a suitable relationship between the factor worths and the steel ship RFR. Typical values are shown in the sample calculation of Appendix J. Assignment of these values must be done with great care, because they can change the overall assessment from "favorable" to "unfavorable" or vice versa if they are chosen poorly.

MATERIAL TRADE-OFF STUDY

FINAL EVALUATION

OF

____

BY ______________________ DATE ______________

ECONOMIC FACTOR	($/TON)
BASE SHIP RFR	
NEW MATERIAL SHIP RFR	
ECONOMIC WORTH	

NON-ECONOMIC FACTORS	MULTI-PLIER ($/TON)	PESSIMISTIC		MOST PROBABLE		OPTIMISTIC	
		RATING	WORTH ($/TON)	RATING	WORTH ($/TON)	RATING	WORTH ($/TON)
SUITABILITY FOR INTENDED USE							
ENVIRONMENTAL IMPACT							
USE OF NATIONAL RESOURCES							
GOVERNMENT INVOLVEMENT							
RISK							
NON-ECONOMIC WORTH							

TOTAL WORTH	WORTH ($/TON)	% OF BASE SHIP RFR
PESSIMISTIC EVALUATION		
MOST PROBABLE EVALUATION		
OPTIMISTIC EVALUATION		

Figure 3

MATERIAL DATA BANK

The term "Material Data Bank" refers to the collection of material information needed to conduct a Material Trade-Off Study. Three types of information are required.

First is basic data on the proposed alternate material and on the steel which it replaces. This includes not only numerical values for things such as "Design Properties", but also descriptive words for things such as "Advantages" and "Disadvantages".

Second is a compilation of the methods to be used for substituting the proposed new material in place of steel for various types of structure. This may consist of design formulas, or of conversion tables and graphs.

Third is supplementary data on the alternate material components. This includes such things as cost, weight, and space comparisons with the steel component which is being replaced.

Basic Data

Figure 4 is an outline of the basic data needed. This format should be used for all basic data to simplify comparisons between materials. Most of the information needed for a new material is readily available but some, such as installed cost data, may have to be developed as part of the Material Trade-Off Study.

Some of the categories shown in Figure 4 may not apply to every material. In this case, the Data Bank entry for that category should be "not applicable" to establish clearly that the category was not omitted inadvertently. Similarly, when information has not been developed, the item should be marked "not available". Some materials may justify additional categories. In this case, the new entries should be added in a logical sequence within the existing outline.

Substitution Method

When sufficient basic data have been collected, a method can be developed for substituting "equivalent" components of the alternate material in place of the steel ship components. As discussed earlier in the section "STRUCTURAL DESIGN DEVELOPMENT", "equivalence" may be different for each combination of loading (shear, tension, etc.) and resistance (equal ultimate load carrying capacity, equal deflection, etc.). A separate substitution formula may, therefore, be required for each such combination.

In many cases, the configuration of a new component will be different from that of the original steel ship. Steel structure usually consists of stiffened plating, I-beams, or pipes. New structure of metal, such as aluminum or high-strength steel, may retain that same general configuration with different stiffener spacing or stiffener shapes, but structure made of other materials, such as reinforced concrete, will be completely different. It is important that the substitution formulas developed in the Data Bank provide for efficient use of the prepared alternate material.

FIGURE 4 - MATERIAL DATA BANK FORMAT

1. Material (Including Condition or Temper)

2. Suitability for Marine Environment

    2.1 Operational Experience
    2.2 Advantages
    2.3 Disadvantages
    2.4 Availability
    2.5 Cost
    2.6 Scrap value

3. Design Properties

    3.1 Design Yield Strength
    3.2 Design Ultimate Strength
    3.3 Modulus of Elasticity
    3.4 Shear Modulus
    3.5 Poisson's Ratio
    3.6 Density
    3.7 Typical Size or Thickness Limitations

4. Fabricability

    4.1 Joining
    4.2 Forming
    4.3 Machining
    4.4 Thermal Treatment
    4.5 Distortion Control

5. Non-Destructive Testing/Quality Control

    5.1 Liquid Penetrant
    5.2 Magnetic Particle
    5.3 Radiography
    5.4 Ultrasonics
    5.5 Acoustical Emission

6. Maintenance and Repair

7. Physical and Chemical Properties

    7.1 Composition
    7.2 Corrosion
    7.3 Erosion
    7.4 Protection
    7.5 Thermal Conductivity
    7.6 Coefficient of Thermal Expansion

FIGURE 4 - MATERIAL DATA BANK FORMAT (CONT.)

8. Mechanical Properties

   8.1 Yield Strength
   8.2 Ultimate Strength
   8.3 Elongation
   8.4 Toughness
   8.5 Hardness
   8.6 Fatigue Strength
   8.7 Creep

9. Miscellaneous

   9.1 Specifications
   9.2 Special Properties
   9.3 Remarks

Two techniques can be used for developing the new material components. In the first of these, the conversion formulas in the Data Bank are used directly to calculate new component scantlings. With the second approach, Data Bank formulas are used to construct tables or graphs showing the equivalency of a systematic series of components covering the range to be investigated. The actual substitution is then made from the appropriate table or curve.

Direct use of the formulas is preferred when the Material Trade-Off Study involves only a single material/ship combination. It is the approach used in the sample calculations of this report. The second approach is preferred when many material/ship combinations are being studied, because it is faster and produces more consistent results.

Supplementary Data

Equivalency information must cover more than scantlings. Other data to be included are:

Weights. This is the installed weight per square foot or per segment. It is used to determine the effect of light ship weight, deadweight and displacement.

Cost. This is the installed cost per square foot, or per pound of material, or per segment. It is used to determine the effect on construction cost and hence on life-cycle ship cost.

Space, This is the amount of space needed by the structural component. Usually it is the depth of the stiffening member plus the plating thickness, but some materials may utilize an unconventional configuration. Space is normally not a factor but may affect the selection in cases such as a container ship where specific clearances must be maintained.

Volume. This is the volume of the structure itself. It is normally not a factor but may affect the selection in cases such as a tanker where the volume of structure affects the usable volume of the tank.

SAMPLE CALCULATION

A sample calculation is included in this report to illustrate the Material Trade-Off Study method. Data needed for the sample calculation were compiled from various published sources and are thought to be reliable. However, the calculation is intended for illustrative purposes only, so no attempt was made to verify the accuracy of that data. In addition, the "non-economic" and "combined evaluation" weighting factors were selected only for illustrative purposes, based on the needs of a hypothetical shipowner, and are not intended as a recommended set of values. For these reasons, the results of the sample calculation should not be construed as a complete evaluation of the selected material.

Aluminum 5456 was used as the proposed new material for this sample calculation. This was selected because much data about it were readily available and because it had been used in a previous study of new hull structures; Reference 4.

Data Bank for Sample Calculation

Appendix C contains the sample Material Data Bank. This appendix has three parts:

Part I. Material properties for steel and aluminum.

Part II. Conversion formulas for converting steel structure to equivalent aluminum structure.

Part III. Supplementary data (weight, cost, space and volume).

Appendix D contains the sample Ship Data Bank. All the available information on the steel ship selected as a base for the Material Trade-Off Study is tabulated in this Data Bank for ready reference.

Material data have been collected for ABS mild steel and for 5456 aluminum, using the format shown in Figure 4. The ABS mild steel data are included to permit side by side comparison of individual items. In addition, where quantitative data are available, the ratio of the aluminum value to the mild steel value is given.

The question of appropriate environmental conditions deserves particular attention in the Material Data Bank. At least four significantly different areas can be identified for a typical ship: the bottom shell which is normally fully immersed in water; the side shell which is alternately immersed depending on the ship loading condition, wave action, and water spray; the deck which is occasionally wetted by waves and water spray; and the internal surfaces which may be subject to corrosion and/or abrasion from various cargoes. In addition, the effects of coatings need to be considered, since a mild-steel ship is usually coated throughout whereas an aluminum ship may not be coated above the waterline or internally.

One area which needs further work, particularly for a bulk carrier, is the abrasion resistance of aluminum. The limited available data indicates that the 5000 series alloys will abrade at approximately four to five times the rate of mild steel. Of course, the required abrasion allowance for various structures will depend on the cargoes to be carried. For highly abrasive bulk cargoes, an analysis may be used to trade off the cost of providing additional abrasion allowance initially against the cost of renewing affected plating periodically.

Another area which needs further development is construction costs. The values given are estimates for typical merchant ship structures. These values can be extended to permit trade-off analyses between different structural systems.

Fatigue is also an area which needs further investigation. The problem here is not a lack of data but rather a lack of guidelines as to what to use, because the variables are so numerous. For example, in the computerized data bank covering fatigue of aluminum alloy weldments at Iowa State University, there are currently sixteen possible specimen types, thirty-two possible joint types, fifty-seven possible special treatments; thirty-three possible welding procedures, and three possible stress ranges for each aluminum alloy and temper.

The fatigue curves used in this study are for butt-welded plates with reinforcement left on, tested in air. For more detailed study of aluminum fatigue problems, the Iowa State University data bank can provide much additional data.

Steel Ship Selection for Sample Calculation

A ship type, cargo and trade route were chosen arbitrarely for the sample calculation:

Ship type = bulk carrier

Cargo = ore

Trade route = Seattle to Yokohama with cargo, and return in ballast.

Based on these requirements, the M. V. CHALLENGER was selected as the steel ship. This vessel had been used in the previous study, Reference 4.

Structural Design Development for Sample Calculation

Appendix E contains the sample calculations needed to synthesize an aluminum ship design based on the steel ship of Appendix D.

The structure of the steel ship was subdivided into major components. The type of loading was determined for each component, and the appropriate conversion formulas selected from Part II of the Material Data Bank. These formulas were used to develop equivalent aluminum components.

All interfaces between the aluminum components were reviewed to ensure compatibility of the new structure. Because both the aluminum and the steel components are basically stiffened plates, and because the stiffener spacing was made the same for both materials, no incompatibilities were found in this sample calculation.

Longitudinal strength was checked to ensure that the strength of the new hull girder was equivalent to that of the steel ship. Hull stiffness was also checked.

Supplementary information on the synthesized ship was developed using the equivalency relationships of Part III of the Material Data Bank. Structural weights were calculated in Appendix E; costs were calculated in Appendix G. Space and volume requirements are not significant for the ship used in the sample calculation, and were not calculated.

Design Optimization for Sample Calculation

Appendix F contains the design optimization calculations for the sample ship. A simple computer program based on the method described earlier in the section "DESIGN OPTIMIZATION" was used. Each of the three options discussed in that section was investigated. These are:

1. Keep the hull and machinery characteristics identical and accept the greater cargo capacity;

2. Reduce the size of the ship and its machinery to make the cargo capacity the same as that of the steel ship;

3. Increase the size of the ship and its machinery to minimize RFR. (This third option was not followed exactly. The cargo capacity was increased 5% to illustrate the effect of such an increase. No attempt was made to increase the capacity enough to minimize RFR.)

For the first option, the aluminum ship characteristics synthesized in Appendix E were used. For the second and third options, a changed cargo capacity was input, and the computer modified the remaining characteristics accordingly. Each of the three designs resulting from this optimization process was subsequently evaluated, both economically and non-economically, and compared with the basic steel ship.

Economic Evaluation for Sample Calculation

Appendix G contains an economic evaluation of the basic steel ship and of each of the three aluminum ships developed in Appendix F. These evaluations used computer program GENEC, described in Appendix A, to calculate the Required Freight Rate (RFR) for each ship. These RFR's are:

SHIP	RFR ($/TON)
Steel ship	9.44
"Same geometry" aluminum ship	9.67
"Same capacity" aluminum ship	9.95
"Increased capacity" aluminum ship	9.46

Costs for the steel ship are tabulated in Appendix D. Costs for the aluminum ships are calculated in Appendix G. Appendix G also lists the economic assumptions and voyage data needed for the RFR analysis.

Costs are divided into four major categories:

Fuel

Acquisition

Operating

Scrap Value (credit)

Fuel costs are calculated by the computer, based on the fuel consumption for each leg of the voyage and for the time in port. These values are not affected by the hull structural material. Fuel cost is given in Part III of the Data Bank.

Acquisition costs are broken down into seven sub-categories:

Structure

Construction Waste Credit

Machinery

Outfit

Design

Overhead

Profit

Information on these costs is given in Part III of the Data Bank.

Operating costs are broken down into five sub-categories:

Manning and Subsistence

Shore Staff

H and M Insurance

P and I Insurance

Maintenance and Repair

Information on these costs is given in Part III of the Data Bank.

Scrap value for aluminum is much greater than it is for steel. It is based on structural weight only, on the assumption that the residual value of machinery and outfit at the end of the ship's life will cover the cost of dismantling the vessel. Cost factors for scrap are given in Part I of the Data Bank.

Non-Economic Evaluation for Sample Calculation

Appendix H contains the non-economic evaluation of aluminum versus steel, using the five evaluation factors described in Appendix B. These evaluations apply equally to all three aluminum ships developed in this sample study. The factor ratings are:

		Rating	
Factor	Pessimistic	Probable	Optimistic
Suitability for Intended Use	- 0.111	- 0.077	- 0.038
Environmental Impact	0	+ 0.033	+ 0.058
Use of National Resources	- 0.137	- 0.066	- 0.009

Factor	Rating Pessimistic	Probable	Optimistic
Government Involvement	- 0.014	+ 0.036	+ 0.133
Risk	- 0.147	- 0.096	- 0.081

This evaluation was performed from the point of view of a hypothetical shipowner. Plus values mean that aluminum is advantageous to him; minus values mean that it is not. If a different point of view had been assumed (perhaps that of the U.S. Maritime Administration), the various attributes might have had different "weights" and would certainly have had different "values", so that the final ratings would have been different.

Combined Evaluation for Sample Calculation

Appendix J contains the combined evaluation of aluminum for the three ship designs developed in the sample study. These final "worths" are expressed in the same terms as RFR ($/ton). Their importance can be assessed by comparing them with the RFR of the basic steel ship (9.44 $/ton). This comparison is:

SHIP TYPE	EVALUATION	WORTH OF ALUM	% OF BASE RFR
same geometry	pessimistic	- 0.41 $/ton	- 4.3
	most probable	- 0.32	- 3.3
	optimistic	- 0.22	- 2.4
same cargo capacity	pessimistic	- 0.69	- 7.3
	most probable	- 0.60	- 6.4
	optimistic	- 0.51	- 5.4
increased cargo capacity	pessimistic	- 0.21	- 2.2
	most probable	- 0.11	- 1.2
	optimistic	- 0.02	- 0.2

These data show that aluminum is not suited to the needs of the hypothetical owner described in the sample calculation, unless he is willing to use a larger (increased cargo capacity) ship. Figure G5 shows that a larger aluminum ship would be advantageous, but the improvement in RFR (and worth) is attributable to size, not material. However, it is probable that a larger ship of steel would be better than the larger ship of aluminum.

RECOMMENDATIONS

Four areas are recommended for further study.

First: The method should be extended to include non-merchant ships. In this extension, the mission of the ship would be defined in non-economic terms, so that the measure of worth of the new material could be expressed without an economic study. Simultaneously an economic study would develop the life-cycle costs of the steel ship and the new ship. The advantage or disadvantage of the new material would then be measured by the ratio of the change in cost to the change in mission effectiveness.

Second: The computer program described in the section "DESIGN OPTIMIZATION" should be developed. This program would permit rational and consistent ship design modifications to meet any specified "optimization" criterion. Such a program would have value for other ship design work in addition to the Material Trade-Off Studies.

Third: The computer program described in the section "EVALUATION OF ECONOMIC FACTORS" should be developed. This program would permit consistent cost estimates to be prepared quickly for use in these and other ship design studies.

Fourth: A complete Material Data Bank should be established for all materials of potential interest in hull structural applications. Information in the sample Material Data Bank of this report would be extended in areas such as abrasion resistance of aluminum, creep, etc.

REFERENCES AND BIBLIOGRAPHY

1. Manning, G. C., The Basic Design of Ships, Van Nostrand Co., New York, 1945.

2. Rules for Building and Classing Aluminum Vessels, American Bureau of Shipping, 1975.

3. Bosworth, T. J., "Trade-off Study for Materials and Fabrication Process for Advanced High Performance Ship Application". Report No. D180-17941-1 Vol. I and II, February, 1974, prepared by the Boeing Aerospace Company for U.S. Naval Ship Systems Command.

4. Attenbury, C. J., Scott, R. J., "Design Considerations for Aluminum Hull Structures - Study of Aluminum Bulk Carrier", Ship Structure Committee Report No. SSC-218, 1971.

5. Welding Kaiser Aluminum, Kaiser Aluminum and Chemical Sales, Inc., 1967.

6. Alcoa Aluminum Handbook, Aluminum Company of America, 1962.

7. Muckle, Professor W., "Materials for Ship Structures", North East Coast Institution of Engineers and Shipbuilders Transactions, July, 1976.

8. Holtyn, Chester H., Greshom, G. Scott, Snodgrass, Jack, Hay, Robert A., and Hawner, Pierre, "The Construction and Service Record of a 306-ft Aluminum Trailership", SNAME Transaction, Vol. 80, 1972.

9. "Iron Age", Chilton Company, published weekly.

10. Materials Engineering "Materials Selector" for 1974, 1975, 1976, 1977.

11. Yutani, N., and Reynolds, T. L., "A Survey of Fastening Techniques for Shipbuilding", Ship Structure Committee Report No. SSC-260, 1976.

12. Parrott, R. G., Ward, S. W., Uttrachi, G. D., "Electroslag Welding Speeds Shipbuilding", Welding Journal, Vol. 53, April, 1974.

13. "American Shipbuilders Turn to Automated Welding to Compete", Welding Engineers, April, 1969.

14. Masubuchi, K., "Materials to Fight Marine Environments", Materials Engineering, Vol. 73, No. 1, January, 1971.

15. Rabian, R. J., and Vaccari, J. A., "How Materials Stand up to Corrosion and Chemical Attack", Materials Engineering, Vol. 73, No. 2, February, 1971.

16. Farrell, T. R., "Chemical Tankers - The Quiet Evolution", Transactions RINA, Vol. 117, 1975.

17. Rules for Building and Classing Steel Vessels, American Bureau of Shipping, 1977.

18. Grant, James E., Dickerson, Paul B., Sharp, Maurice L., Wolff, Norman P., Yanok, George P., "Considerations for the Structural Detailing of Aluminum Ships", Final Report prepared by the Aluminum Company of America for the Naval Ship Engineering Center, November, 1974.

19. Sanders, W. W., Jr., "Fatigue Behavior of Aluminum Alloy Weldments", Welding Research Council Bulletin No. 171, April, 1972.

20. Masubuchi, K., "Residual Stresses and Distortion in Welded Aluminum Structures and their Effects on Service Performance", Welding Research Council Bulletin No. 174, July, 1972.

21. Lawrence, F. V., Jr., and Munse, W. H., "Effects of Porosity on the Tensile Properties of 5083 and 6061 Aluminum Alloy Weldments", Welding Research Council Bulletin No. 181, February, 1973.

22. Saunders, W. W., Jr., and Gannon, S. M., "Fatigue Behavior of Aluminum Alloy 5083 Butt Welds", Welding Research Council Bulletin No. 199, October, 1974.

23. Lawrence, F. V., Jr., Munse, W. H., and Burk, J. D., "Effects of Porosity on the Fatigue Properties of 5083 Aluminum Alloy Weldments", Report for U.S. Naval Sea Systems Command, December, 1974.

24. "Aluminum Fire Protection Guidelines", SNAME Hull Structure Report No. 2-21, 1974.

25. "Formulas for Stress and Strain", Raymond J. Roark and Warren C. Young, 5th Edition.

26. Benford, H., "Measures of Merit for Ship Design", SNAME Marine Technology, Vol. 7 No. 4, October 1970.

APPENDIX A

ECONOMIC EVALUATION

COMPUTER PROGRAM

CONTENTS

INTRODUCTION

Computer program "GENEC" is a generalized mathematical model for evaluating the economic viability of a cargo ship or tanker. It is written in timesharing BASIC for the NNS Honeywell 6080 computer. Figure A1 is a listing of the program, and Figure A2 is an index of the symbols used.

The measure of Merit (MM) developed by this math model can be either Required Freight Rate (RFR) or Net Present Value (NPV). RFR is used for Material Trade-Off Studies. In either case the resulting MM should be compared only with competing Measures of Merit calculated by this or a similar program because the absolute value of any MM is highly dependent on various economic assumptions implicit in the math model used. The relative position of competing systems will remain the same when they are analyzed by any math model using consistent economic assumptions, but comparisons between competing systems which have been analyzed by different models may cause an apparent change in this ranking. RFR can vary as much as 40 or 50% if different (but equally reasonable and valid) assumptions are used for such things as frequency and timing of cost payments or income receipts, escalation, taxes, etc.

PROGRAM THEORY

This math model is based on a Discounted Cash Flow (DCF) analysis of all the costs and income involved in acquiring, owning and operating a ship over its total life or over any selected portion of its life. Income and costs are collected by months, with all transactions in a given month assumed to occur at the end of that month. Transactions which occur on known dates (such as construction payments or insurance premiums) are included with other costs for the month in which they occur; transactions which occur at unpredictable times (such as fuel costs, port charges, income, repair costs, etc.) are distributed uniformly over the months of the year in which they occur.

Costs are identified as "capitalized" or "operating". This distinction has no effect when the economic study covers the entire life of the ship; it is needed only when the study is limited to a part of that life. Operating costs which occur during the period being studied are included in the analysis; operating costs which do not occur during that period are ignored. Capitalized expenditures, regardless of when they occur, are amortized over the full life of the ship, producing a uniform monthly cost. When this uniform cost is applied to periods shorter than the ship life, it will not completely amortize the capital expenditures. The assumption is that the remaining amortization is accomplished during the remaining months of useful ship life.

No provision is made for the effects of taxes, or of such tax-related stratagems as leveraged leasing, because these effects depend on owner-related circumstances which are not governed by ship design. Each prospective owner must, therefore, evaluate his own tax situation.

Every dollar value used in this math model can be escalated, with a different annual rate for each. These rates remain constant for the life of the ship. Date of contract is the base date for calculating escalation, using the formula:

```
*LIST GENEC

10 DIM C1(50),C3(50),C4(5),D(50),D2(50),D3(50),E(50),F1(50),F2(50)
20 DIM F3(50),F4(50),F5(50),K3(5),K4(5),M(5,100),N$(50),P(5,100)
30 DIM P1(50),R(50),W1(50),W2(50),W3(50),W4(50),Z(50,16)
40 FILES *
50 DEF FNE(X)=(1+X/100)^((K-1)/12)
60 DEF FNP(X)=D(J)+C*(1+X/100)^((1-K)/12)
70 REM+++++++++++++++++++++++++ DATA INPUT ++++++++++++++++++++++++
80 PRINT "DATA FILE ";
90 INPUT F$
100 IF F$<>"STOP" THEN 120
110 STOP
120 FILE #1,F$
130 M1=0
140 P1(1)=0
150 READ #1,F1$,N1$
160 FOR I=1 TO 16
170 READ #1,Z(1,I)
180 NEXT I
190 FOR J=2 TO Z(1,1)+1
200 P1(J)=0
210 READ #1,N$(J)
220 FOR I=1 TO 12
230 READ #1,Z(J,I)
240 NEXT I
250 NEXT J
260 T1=0
270 FOR J=Z(1,1)+2 TO Z(1,1)+Z(1,2)+Z(1,3)+1
280 P1(J)=0
290 READ #1,N$(J)
300 FOR I=1 TO 10
310 READ #1,Z(J,I)
320 NEXT I
330 IF Z(J,9)<4 THEN 420
340 T1=T1+1
350 IF T1<6 THEN 380
360 PRINT "TOO MANY IRREGULAR PAYMENT SCHEDULES"
370 GO TO 80
380 P1(J)=T1
390 FOR I=1 TO Z(J,10)
400 READ #1,M(P1(J),I),P(P1(J),I)
410 NEXT I
420 NEXT J
430 RESTORE #1
440 REM+++++++++++++++++++++++++ DATA MODIFICATION ++++++++++++++++
450 PRINT F1$
460 LET T$=CLK$
470 LET D$=DAT$
480 PRINT "NEW DATA",T$,D$
490 INPUT T1,T2,T3
500 IF T1=0 THEN 640
510 M1=1
520 Z(T1,T2)=T3
530 IF T1<Z(1,1)+2 THEN 490
540 IF T2<>9 THEN 490
550 IF T3<4 THEN 490
560 PRINT "HOW MANY CHANGES";
570 INPUT T4
580 FOR I=1 TO T4
590 INPUT T5,T6,T7
600 M(P1(T1),T5)=T6
610 P(P1(T1),T5)=T7
620 NEXT I
630 GO TO 490
640 REM+++++++++++++++++++++++++ DAYS/VOYAGE ++++++++++++++++++++++
650 D4=0
660 FOR J=2 TO Z(1,1)+1
670 D2(J)=Z(J,1)
680 D3(J)=Z(J,2)/(24*Z(J,3))
690 D4=D4+D2(J)+D3(J)
700 NEXT J
710 V1=Z(1,8)/D4
720 REM+++++++++++++++++++++++++ FUEL +++++++++++++++++++++++++++++
730 F=0
740 FOR J=2 TO Z(1,1)+1
750 F2(J)=Z(J,1)*Z(J,4)
760 F5(J)=D3(J)*Z(J,5)
770 F=F+F2(J)+F5(J)
780 NEXT J
790 F2(Z(1,1)+2)=F2(2)
800 F1(2)=F2(2)
810 T1=0
820 FOR J=2 TO Z(1,1)+1
830 F4(J)=F1(J)-F2(J)
840 F3(J)=0
850 IF Z(J,6)=0 THEN 880
860 F3(J)=F
870 F4(J)=F4(J)+F
880 IF F4(J)=>F2(J+1)+F5(J)-.1 THEN 930
890 F3(J)=F2(J+1)+F5(J)-F4(J)+T1
900 PRINT USING 910,F3(J),N$(J)
910:SHIP MUST LOAD ##### TONS OF FUEL AT 'LLLLLLLLLLLLL
920 F4(J)=F2(J+1)+F5(J)
930 IF F4(J)+Z(1,13)<=Z(1,14) THEN 970
940 F3(J)=F3(J)+Z(1,14)-F4(J)-Z(1,13)
950 PRINT "SHIP CAN ONLY LOAD";F3(J);"TONS OF FUEL AT ";N$(J)
960 F4(J)=Z(1,14)
970 F1(J+1)=F4(J)-F5(J)
930 IF F1(J+1)=>0 THEN 1010
990 PRINT "OUT OF FUEL AFTER ";N$(J)
1000 GO TO 440
```

FIGURE A-1 - COMPUTER PROGRAM "GENEC"

```
1010 IF F1(J+1)=>F2(J+1)-.1 THEN 1050
1020 T1=F2(J+1)-F1(J+1)
1030 F1(J+1)=F2(J+1)
1040 GO TO 1060
1050 T1=0
1060 C1(J)=0
1070 IF F3(J)=0 THEN 1120
1080 C1(J)=F3(J)*Z(J,7)
1090 IF Z(J,7)>0 THEN 1120
1100 PRINT "NO COST DATA FOR FUEL AT ";N$(J)
1110 GO TO 440
1120 NEXT J
1130 IF T1=0 THEN 1160
1140 PRINT USING 910,T1,N$(2)
1150 F3(2)=F3(2)+T1
1160 REM+++++++++++++++++++++++++ CARGO & BALLAST ++++++++++++++++++
1170 W=Z(1,9)-Z(1,11)-Z(1,12)-Z(1,13)
1180 W3(1)=Z(2,10)
1190 FOR J=2 TO Z(1,1)+1
1200 W1(J)=Z(J,9)
1210 W2(J)=Z(J,10)
1220 IF W2(J)<=W3(J-1) THEN 1250
1230 W2(J)=W3(J-1)
1240 PRINT "SHIP CAN ONLY OFFLOAD";W2(J);"TONS OF CARGO AT ";N$(J)
1250 IF W2(J)=>0 THEN 1270
1260 W2(J)=W3(J-1)
1270 IF W1(J)=>0 THEN 1290
1280 W1(J)=W-F4(J)-W3(J-1)+W2(J)
1290 W3(J)=W3(J-1)+W1(J)-W2(J)
1300 IF W3(J)<=W-F4(J) THEN 1340
1310 W1(J)=W-F4(J)+W2(J)-W3(J-1)
1320 PRINT "SHIP CAN ONLY LOAD";W1(J);"TONS OF CARGO AT ";N$(J)
1330 W3(J)=W3(J-1)+W1(J)-W2(J)
1340 W4(J)=Z(1,10)-Z(1,11)-Z(1,12)-Z(1,13)-F4(J)-W3(J)
1350 IF W4(J)=>0 THEN 1370
1360 W4(J)=0
1370 NEXT J
1380 REM+++++++++++++++++++++++++ CASH FLOW ++++++++++++++++++++++
1390 D1=0
1400 D5=0
1410 E1=0
1420 E2=0
1430 K1=Z(1,5)+12*(Z(1,15)-1)+2
1440 K2=Z(1,5)+12*Z(1,16)+1
1450 FOR J=2 TO Z(1,1)+1
1460 D(J)=0
1470 E(J)=0
1480 FOR K=K1 TO K2
1490 C=C1(J)+V1*FNE(Z(J,8))/12
1500 D(J)=FNP(Z(1,4))
1510 C2=W2(J)*V1*FNE(Z(J,12))/12
1520 E(J)=E(J)+C2*(1+Z(1,4)/100)^((1-K)/12)
1530 NEXT K
1540 D1=D1+D(J)
1550 IF Z(J,11)<0 THEN 1590
1560 E1=E1+E(J)*Z(J,11)
1570 R(J)=Z(J,11)
1580 GO TO 1600
1590 E2=E2+E(J)
1600 NEXT J
1610 FOR J=Z(1,1)+2 TO Z(1,1)+Z(1,2)+1
1620 D(J)=0
1630 IF Z(J,3)=>0 THEN 1660
1640 C3(J)=V1*Z(J,1)/12
1650 GO TO 1700
1660 IF Z(J,3)>0 THEN 1690
1670 C3(J)=Z(J,1)*Z(J,4)
1680 GO TO 1700
1690 C3(J)=Z(J,1)*Z(Z(J,3),Z(J,4))
1700 FOR I=5 TO 7 STEP 2
1710 IF Z(J,I)=>0 THEN 1740
1720 C3(J)=C3(J)/Z(J,I+1)
1730 GO TO 1780
1740 IF Z(J,I)>0 THEN 1770
1750 C3(J)=C3(J)*Z(J,I+1)
1760 GO TO 1780
1770 C3(J)=C3(J)*Z(Z(J,I),Z(J,I+1))
1780 NEXT I
1790 ON Z(J,9) GO TO 1800,1840,1840,1890
1800 K=Z(J,10)+1
1810 C=C3(J)*FNE(Z(J,2))
1820 D(J)=FNP(Z(1,4))
1830 GO TO 1940
1840 FOR K=1+(Z(J,9)-2)*Z(J,10) TO Z(1,5)+(Z(J,9)-2) STEP Z(J,10)
1850 C=C3(J)*FNE(Z(J,2))
1860 D(J)=FNP(Z(1,4))
1870 NEXT K
1880 GO TO 1940
1890 FOR I=1 TO Z(J,10)
1900 K=1+M(P1(J),I)
1910 C=C3(J)*FNE(Z(J,2))*P(P1(J),I)/100
1920 D(J)=FNP(Z(1,4))
1930 NEXT I
1940 D5=D5+D(J)
1950 NEXT J
1960 FOR J=Z(1,1)+Z(1,2)+2 TO Z(1,1)+Z(1,2)+Z(1,3)+1
1970 D(J)=0
1980 IF Z(J,3)=>0 THEN 2010
1990 C3(J)=V1*Z(J,1)/12
2000 GO TO 2050
2010 IF Z(J,3)>0 THEN 2040
2020 C3(J)=Z(J,1)*Z(J,4)
2030 GO TO 2050
2040 C3(J)=Z(J,1)*Z(Z(J,3),Z(J,4))
2050 FOR I=5 TO 7 STEP 2
2060 IF Z(J,I)=>0 THEN 2090
2070 C3(J)=C3(J)/Z(J,I+1)
2080 GO TO 2130
2090 IF Z(J,I)>0 THEN 2120
2100 C3(J)=C3(J)*Z(J,I+1)
2110 GO TO 2130
2120 C3(J)=C3(J)*Z(Z(J,I),Z(J,I+1))
2130 NEXT I
```

FIGURE A-1 (CONT.) - COMPUTER PROGRAM "GENEC"

```
2140 ON Z(J,9) GO TO 2150,2210,2210,2260
2150 K=Z(J,10)+1
2160 IF K<K1 THEN 2340
2170 IF K>K2 THEN 2340
2180 C=C3(J)*FNE(Z(J,2))
2190 D(J)=FNP(Z(1,4))
2200 GO TO 2330
2210 FOR K=K1+(Z(J,9)-2)*Z(J,10)-1 TO K2+(Z(J,9)-2)-1 STEP Z(J,10)
2220 C=C3(J)*FNE(Z(J,2))
2230 D(J)=FNP(Z(1,4))
2240 NEXT K
2250 GO TO 2330
2260 FOR I=1 TO Z(J,10)
2270 K=Z(1,5)+M(P1(J),I)+1
2280 IF K<K1 THEN 2320
2290 IF K>K2 THEN 2320
2300 C=C3(J)*FNE(Z(J,2))*P(P1(J),I)/100
2310 D(J)=FNP(Z(1,4))
2320 NEXT I
2330 D1=D1+D(J)
2340 NEXT J
2350 R1=0
2360 T1=1+Z(1,4)/100
2370 A1=12*T1^((Z(1,5)+1)/12)*((1/T1)^(1/12)-1)/((1/T1)^Z(1,6)-1)
2380 A2=12*T1^((Z(1,5)+12*(Z(1,15)-1)+1)/12)*((1/T1)^(1/12)-1)
2390 A2=A2/((1/T1)^(Z(1,16)-Z(1,15)+1)-1)
2400 IF E2=0 THEN 2420
2410 R1=(D1+D5*A1/A2-E1)/E2
2420 REM+++++++++++++++++++++++++ OUTPUT +++++++++++++++++++++++++
2430 PRINT
2440 PRINT "OUTPUT ";
2450 INPUT T1
2460 PRINT
2470 ON T1 GO TO 70,440,2580,2920,3430,3460
2480 REM+++++++++++++++++++++++++ SUBROUTINE FOR HEADINGS ++++++++++
2490 PRINT N1$
2500 PRINT "      DATA FILE: ";F$
2510 PRINT "      ";F1$
2520 IF M1=0 THEN 2540
2530 PRINT "      FILE MODIFIED AT ";T$;" ON ";D$
2540 PRINT USING 2550,Z(1,15),Z(1,16)
2550:EXPENSES FOR YEARS ## THRU ## AFTER DELIVERY USED IN THIS ANALYSIS
2560 PRINT
2570 RETURN
2580 REM+++++++++++++++++++++++++ VOYAGE DATA +++++++++++++++++++++
2590 GOSUB 2490
2600 FOR J=2 TO Z(1,1)+1
2610 PRINT N$(J)
2620 PRINT "DAYS IN PORT=";D2(J)
2630 PRINT "      FUEL CONSUMED=";F2(J);"TONS"
2640 PRINT "NEXT LEG OF VOYAGE=";Z(J,2);"MILES AT";Z(J,3);"KNOTS"
2650 PRINT "      DAYS AT SEA=";D3(J)
2660 PRINT "      FUEL CONSUMED=";F5(J);"TONS"
2670 PRINT "CARGO-OFFLOADED=";W2(J);"TONS"
2680 PRINT "      -LOADED   =";W1(J);"TONS"
2690 PRINT "FUEL-LOADED=";F3(J);"TONS"
2700 PRINT "DEPARTURE WEIGHTS"
2710:     CREW & STORES=######### TONS
2720:     FRESH WATER  =######### TONS
2730:     BALLAST      =######### TONS
2740:     SERVICE FUEL =######### TONS
2750:     RESERVE FUEL =######### TONS
2760:     CARGO        =######### TONS
2770:        TOTAL     =######### TONS
2780:MAXIMUM DEADWEIGHT=######### TONS
2790 PRINT USING 2710,Z(1,11)
2800 PRINT USING 2720,Z(1,12)
2810 PRINT USING 2730,W4(J)
2820 PRINT USING 2740,F4(J)
2830 PRINT USING 2750,Z(1,13)
2840 PRINT USING 2760,W3(J)
2850 PRINT USING 2770,Z(1,9)-W+F4(J)+W3(J)+W4(J)
2860 PRINT USING 2780,Z(1,9)
2870 PRINT
2880 NEXT J
2890 PRINT "TOTAL DAYS, ROUND TRIP=";D4
2900 PRINT "AVERAGE NUMBER OF TRIPS PER YEAR=";V1
2910 GO TO 2420
2920 REM+++++++++++++++++++++++++ PRESENT VALUES +++++++++++++++++
2930 GOSUB 2490
2940:          PORT          TONS DELIV.   $/TON    ESCAL.   PRES.VAL.
2950:                         PER YEAR                 %      ($1000)
2960:     'LLLLLLLLLLLLL    ########     ###.##   ##.##    ########
2970:          TOTAL       ##########                     ############
2980:          ITEM              AVG.ANN.  ESCAL.   % OF   PRES.VAL.     RFR
2990:                            ($1000)    (%)    TOTAL    ($1000)      ($)
3000:FUEL AT 'LLLLLLLLLLLLL     ########  ##.##   ##.##   ########    ##.##
3010:'LLLLLLLLLLLLLLLLLLLL      ########  ##.##   ##.##   ########    ##.##
3020:          TOTAL         ###########                ###########  ###.##
3030 PRINT "<<<<< INCOME >>>>>"
3040 PRINT USING 2940
3050 PRINT USING 2950
3060 T1=0
3070 T2=0
3080 FOR J=2 TO Z(1,1)+1
3090 IF Z(J,11)=>0 THEN 3110
3100 R(J)=R1
3110 PRINT USING 2960,N$(J),W2(J)*V1,R(J),Z(J,12),E(J)*R(J)/1000
3120 T1=T1+W2(J)*V1
3130 T2=T2+E(J)*R(J)
3140 NEXT J
3150 PRINT USING 2970,T1,T2/1000
3160 PRINT
3170 PRINT "<<<<< EXPENSES >>>>>"
3180 PRINT USING 2980
3190 PRINT USING 2990
3200 T1=0
3210 FOR J=2 TO Z(1,1)+1
3220 T4=100*A2*D(J)/(A2*D1+A1*D5)
3230 PRINT USING 3000,N$(J),A2*D(J)/1000,Z(J,8),T4,D(J)/1000,T4*R1/100
3240 T1=T1+A2*D(J)
3250 NEXT J
```

FIGURE A-1 (CONT.) - COMPUTER PROGRAM "GENEC"

```
3260 FOR J=Z(1,1)+2 TO Z(1,1)+Z(1,2)+1
3270 T4=100*A1*D(J)/(A2*D1+A1*D5)
3280 T3=A1*D(J)/(A2*1000)
3290 PRINT USING 3010,N$(J),A1*D(J)/1000,Z(J,2),T4,T3,T4*R1/100
3300 T1=T1+A1*D(J)
3310 NEXT J
3320 FOR J=Z(1,1)+Z(1,2)+2 TO Z(1,1)+Z(1,2)+Z(1,3)+1
3330 T4=100*A2*D(J)/(A2*D1+A1*D5)
3340 PRINT USING 3010,N$(J),A2*D(J)/1000,Z(J,2),T4,D(J)/1000,T4*R1/100
3350 T1=T1+A2*D(J)
3360 NEXT J
3370 PRINT USING 3020,T1/1000,(D1+A1*D5/A2)/1000,R1
3380 PRINT
3390 IF E2<>0 THEN 3430
3400:NET PRESENT VALUE=########000 $
3410 PRINT USING 3400,(T2-D1-A1*D5/A2)/1000
3420 GO TO 2420
3430 REM++++++++++++++++++++++++++ RFR ++++++++++++++++++++++++++++++
3440 PRINT "CALCULATED RFR=";R1;"$/TON AT DATE OF CONTRACT"
3450 GO TO 2420
3460 REM++++++++++++++++++++++++++ COSTS BY MONTHS +++++++++++++++++
3470 PRINT "WHAT ACCOUNTS ";
3480 INPUT T1,T2,T3,T4,T5
3490 PRINT "WHAT MONTHS ";
3500 INPUT T6,T7
3510 PRINT
3520 GOSUB 2490
3530 PRINT "<<<<< COSTS BY MONTHS >>>>>"
3540 PRINT USING 3550,N$(T1),N$(T2),N$(T3),N$(T4),N$(T5)
3550:MONTH 'RRRRRRRRRR 'RRRRRRRRRR 'RRRRRRRRRR 'RRRRRRRRRR 'RRRRRRRRRR
3560:####  ############ ############ ############ ############ ############
3570 IF T6>0 THEN 3590
3580 T6=0
3590 IF T7<Z(1,5)+12*Z(1,6) THEN 3610
3600 T7=Z(1,5)+12*Z(1,6)
3610 FOR K=T6+1 TO T7+1
3620 J=T1
3630 I=1
3640 GOSUB 3840
3650 J=T2
3660 I=2
3670 GOSUB 3840
3680 J=T3
3690 I=3
3700 GOSUB 3840
3710 J=T4
3720 I=4
3730 GOSUB 3840
3740 J=T5
3750 I=5
3760 GOSUB 3840
3770 PRINT USING 3560,K-1,C4(1),C4(2),C4(3),C4(4),C4(5)
3780 IF K<>K1-1 THEN 3800
3790 PRINT "+++++FIRST MONTH OF OPERATING EXPENSES INCLUDED IN ANALYSIS"
3800 IF K<>K2 THEN 3820
3810 PRINT "+++++LAST MONTH OF OPERATING EXPENSES INCLUDED IN ANALYSIS"
3820 NEXT K
3830 GO TO 2420
3840 REM++++++++++++++++++++++++++ SUBROUTINE FOR MONTHLY COSTS +++++
3850 C4(I)=0
3860 IF J>Z(1,1)+1 THEN 3900
3870 IF K<Z(1,5)+2 THEN 3890
3880 C4(I)=C1(J)*V1*FNE(Z(J,8))/12
3890 RETURN
3900 IF K>T6+1 THEN 3950
3910 K3(I)=1
3920 K4(I)=1
3930 IF J<Z(1,1)+Z(1,2)+2 THEN 3950
3940 K3(I)=Z(1,5)+1
3950 ON Z(J,9) GO TO 3960,3990,3990,4050
3960 IF K<>Z(J,10)+1 THEN 3980
3970 C4(I)=C3(J)*FNE(Z(J,2))
3980 RETURN
3990 IF K<>K3(I)+Z(J,9)-2 THEN 4040
4000 IF J>Z(1,1)+Z(1,2)+1 THEN 4020
4010 IF K>Z(1,5)+1 THEN 4040
4020 C4(I)=C3(J)*FNE(Z(J,2))
4030 K3(I)=K3(I)+Z(J,10)
4040 RETURN
4050 IF K4(I)>Z(J,10) THEN 4100
4060 IF K<M(P1(J),K4(I))+K3(I) THEN 4100
4070 IF K>M(P1(J),K4(I))+K3(I) THEN 4110
4080 C4(I)=C3(J)*FNE(Z(J,2))*P(P1(J),K4(I))/100
4090 K4(I)=K4(I)+1
4100 RETURN
4110 K4(I)=K4(I)+1
4120 GO TO 4050
```

FIGURE A-1 (CONT.) - COMPUTER PROGRAM "GENEC"

D$	Date of program execution
F$	Name of data file
F1$	Identification of data file
N$(J)	Name of account (J)
N1$	Name of ship
T$	Time of program execution
A1	Average annual cost coefficient (capitalized costs)
A2	Average annual cost coefficient (operating costs)
C	Escalated Cost
C1(J)	Cost of fuel per voyage, not escalated, port (J)
C2	Escalated value of tons of cargo off-loaded
C3(J)	Basic monthly cost account (J)
C4(I)	Monthly cost output column (I)
D(J)	Discounted value of cost account (J)
D1	Total discounted value of all operating cost accounts
D2(J)	Days in port (J)
D3(J)	Days at sea after port (J)
D4	Days per round trip
D5	Total discounted value of all capitalized cost accounts
E(J)	Discounted value of tons of cargo off-loaded at port (J)
E1	Total discounted dollar value of cargo off-loaded at ports with specified freight rates
E2	Total discounted value of tons of cargo off-loaded at ports with unspecified freight rate
F	Total tons of fuel used for round trip
F1(J)	Tons of fuel on board, arriving port (J)
F2(J)	Tons of fuel burned, in port (J)
F3(J)	Tons of fuel loaded, port (J)
F4(J)	Tons of fuel on board, leaving port (J)
F5(J)	Tons of fuel burned, at sea after port (J)
I	Index
J	Account
K	Month (date of contract = 1)
K1	First month for cost calculation
K2	Last month for cost calculation
K3(I)	Index for monthly cost subroutine column (I)
K4(I)	Index for monthly cost subroutine column (I)
M(J,I)	Month cost is incurred, account (J), Table "A" line (I)
M1	Index for modifications to data file
P(J,I)	Percentage of total cost, account (J), Table "A" line (I)
P1(J)	Index for irregular payment schedule account (J)
R(J)	Freight rate (not escalated), port (J)
R1	Required Freight Rate (RFR), not escalated
T1/T7	Temporary variables
V1	Round trips per year
W	Weight of fuel + cargo + ballast
W1(J)	Tons of cargo loaded, port (J)
W2(J)	Tons of cargo off-loaded, port (J)
W3(J)	Tons of cargo on board, leaving port (J)
W4(J)	Tons of ballast on board, leaving port (J)
Z(J,I)	Input data, account (J), input data sheet line (I)

FIGURE A-2 - COMPUTER PROGRAM "GENEC" LIST OF SYMBOLS

$$E = B\left(1 + \frac{i}{100}\right)^{\frac{m}{12}}$$

where;

E = Escalated value

B = Base value

i = Annual rate (%)

m = Months from date of contract

Required Freight Rate (RFR) is defined as "that freight rate which will make the present value of all income equal to the present value of all expenses." It can be calculated for all the cargo delivered in a round voyage, or it will be calculated for some of that cargo (delivered at one or more ports of a multi-leg voyage) when freight rates are specified for the remaining cargo, using the formula:

$$RFR = \frac{P_c - P_i}{P_d}$$

where;

RFR = Required Freight Rate ($/ton)

P_c = Present value of costs ($)

P_i = Present value of specified income ($)

P_d = Present value of cargo delivered (tons)

Net Present Value (NPV) is defined as "the difference between the present value of all income and the present value of all expenses." It is calculated when freight rates are specified for all the cargo delivered in a round voyage.

Date of contract is the base date for calculating present value, using the formula:

$$P = \frac{F}{\left(1 + \frac{i}{100}\right)^{\frac{m}{12}}}$$

where;

P = Present value

F = Future value

i = Annual discount rate (%)

m = Months from date of contract

Both "escalation" and "present value" normally refer to the dollar value of a transaction. When the RFR is to be calculated, however, it is convenient to apply these formulas to the tons of cargo off-loaded. The resulting numbers can then be multiplied by RFR (when it has been determined) to get the corresponding values for income.

Average annual cost for a capitalized expense is defined as "the uniform annual cost, payable in equal monthly installments over the operating life of the ship, which would have the same present value as all expenses of the capitalized cost account." It is calculated by the formula:

$$A = P \left\{ \frac{12 \left[\left(1 + \frac{i}{100}\right)^{\left(\frac{m+1}{12}\right)} \right] \left[\frac{1}{\left(1 + \frac{i}{100}\right)^{\left(\frac{1}{12}\right)}} - 1 \right]}{\left[\frac{1}{\left(1 + \frac{i}{100}\right)^{(Y)}} - 1 \right]} \right\}$$

where;

A = Average annual costs ($)

P = Present value of account ($)

i = Discount rate (%)

m = Months from contract to delivery

Y = Years of ship life

Average annual cost for an operating expense is defined as "the uniform annual cost, payable in equal monthly installments over a specified period of the life of the ship, which would have the same present value as all expenses incurred during that period by the operating cost account." It is calculated by the formula:

$$A = P \left\{ \frac{12\left[\left(1+\frac{i}{100}\right)^{\left(\frac{m+1}{12} + Y1 - 1\right)}\right]\left[\frac{1}{\left(1+\frac{i}{100}\right)^{(1/12)}} - 1\right]}{\left[\frac{1}{\left(1+\frac{i}{100}\right)^{(Y2 - Y1 + 1)}} - 1\right]} \right\}$$

where;

A = Average annual cost ($)

P = Present value of account ($)

i = Discount rate (%)

m = Months from contract to delivery

Y1 = First year (after delivery) of period being studied

Y2 = Last year (after delivery) of period being studied

PROGRAM DESCRIPTION

The math model used for program "GENEC" is very flexible. It will accept a round voyage touching at any number of ports, with fueling and cargo loading or off-loading at any of them. The amount of fuel to be loaded can be specified, or the program will calculate the amount needed for the total voyage or for the trip to the next port (plus the fuel needed in that port). The amount of cargo to be handled can be specified, or the program will calculate the maximum that can be loaded or off-loaded. The freight rate for cargo off-loaded at each port can be specified, or the program will calculate RFR.

The program will accept any number of cost accounts. Currently, the sum of the number of ports and the number of cost accounts is limited to 49 by the dimension statements of the program. Each cost account can be "tailored" to any desired conditions by appropriate choices of input data. The amount of the cost is the product of four factors which may be individually specified or may be referenced to other accounts and line numbers. The date of payment may be specified as "per voyage," or "regularly" at the start (or end) of specified periods before or after dlivery, or "irregularly" at any number of specified dates. Currently, the number of irregular payment schedules is limited to five, and the number of dates per schedule is limited to 100 by the dimension statements of the program.

The number of round trips per year is determined by adding the number of days in port and the number of days at sea for each leg of the voyage to get the total days per trip. This number divided into the average number of operating days per year gives the average number of trips per year. These trips, together with the associated income and costs, are assumed to be distributed uniformly among the twelve months of the year.

Fuel consumed per trip is determined by adding the fuel used in port and the fuel used at sea for each leg of the voyage. The program checks to be sure that there always is enough service fuel on board to reach the next port, and that the amount of fuel on board (including Reserve F.O.) never exceeds the capacity of the F.O. tanks.

The maximum amount of cargo that can be transported on any leg of the voyage is equal to the total deadweight minus the weight of crew and stores, fresh water, service fuel oil when leaving port, and reserve fuel oil. The program checks to be sure that this amount is not exceeded. It will add ballast as necessary to permit safe operation in light condition.

INPUT

Program "GENEC" requires a separate data file. Figure A3 shows the four input data sheets used for this file, and Figure A4 is a listing of a sample file. Any number of such data files may be prepared and saved. They are used one at a time and are identified as needed during program execution (see the section on OPERATION, below).

Each data file has line numbers separated by one blank space from the succeeding data items (these line numbers are not used by the program). Data items are separated by commas, with a comma at the end of each line. Alphanumeric data (items numbered with Roman numerals on the input data sheets) are enclosed in quotation marks. Item numbers on the input data sheets are not used in the data file, but are used when modifying data during program execution (see the section on OPERATION, below).

OUTPUT

Program "GENEC" can produce any or all of the four sets of output shown in Figures A5, A6, A7, and A8 (identified as Type 3, Type 4, Type 5 and Type 6), as selected during program execution (see the section on OPERATION, below).

Figure A5 shows the output identified as Type 3. It contains four blocks of data. The first block identifies the data file used. The next two blocks give information on each port visited and on the sea trip to the next port. (If the data file had held information on more than two ports then there would have been more than two such blocks of output. There must be at least two ports.) The final block gives the total time per round trip and the number of trips per year.

Figures A6 and A7 show the output identified as Type 4. This output also contains four blocks of data. The first block identifies the data file used. The second block, "INCOME," shows the amount of cargo off-loaded at each port, its freight rate, escalation, and present value. It also gives the total present value of all income. The third block, "EXPENSES," gives the average annual cost, escalation, and present value of each expense account. It also gives the total present value of all expenses, the percentage share of that total

ITEM	DESCRIPTION		UNITS	QUANTITY
I	FILE IDENT.	F I L E S A V E D A T	O N	/ /
II	SHIP IDENT.			
1	NUMBER OF "PORT" ACCOUNTS		INTEGER	
2	NUMBER OF CAPITALIZED "COST" ACCOUNTS		INTEGER	
3	NUMBER OF OPERATING "COST" ACCOUNTS		INTEGER	
4	DISCOUNT RATE		%/YEAR	
5	MONTHS FROM CONTRACT TO DELIVERY		MONTHS	
6	SHIP LIFE		YEARS	
7	NUMBER OF MEN IN CREW		INTEGER	
8	OPERATING DAYS PER YEAR		DAYS	
9	MAXIMUM DEADWEIGHT (FULLY LOADED)		TONS	
10	MINIMUM DEADWEIGHT (BALLASTED)		TONS	
11	WEIGHT-CREW & STORES		TONS	
12	-FRESH WATER		TONS	
13	-RESERVE FUEL OIL		TONS	
14	MAXIMUM CAPACITY OF FUEL OIL TANKS		TONS	
15	FIRST YEAR (AFTER DELIVERY) OF PERIOD TO BE ANALYZED		INTEGER	
16	LAST YEAR (AFTER DELIVERY) OF PERIOD TO BE ANALYZED		INTEGER	

FIGURE A-3 - PROGRAM "GENEC" INPUT DATA FORMS

ITEM	DESCRIPTION	UNITS	QUANTITY
I	NAME OF PORT		
1	DAYS IN PORT	DAYS	
2	DISTANCE TO NEXT PORT	N. MILES	
3	SPEED TO NEXT PORT	KNOTS	
4	FUEL CONSUMPTION – IN PORT	TONS/DAY	
5	– AT SEA	TONS/DAY	
6	FUEL – LOADED AT THIS PORT	(NOTE 1)	
7	– COST	$/TON	
8	– ESCALATION	%/YEAR	
9	CARGO – LOADED AT THIS PORT	(NOTE 2)	
10	– OFFLOADED AT THIS PORT	(NOTE 2)	
11	– FREIGHT RATE	(NOTE 3)	
12	– ESCALATION	%/YEAR	

NOTES

1. VALUES GIVEN FOR ITEM 6 MEAN:
   (0) = NO FUEL LOADED.
   (-1) = ALL REQUIRED FUEL LOADED.

2. VALUES GIVEN FOR ITEMS 9 & 10 MEAN:
   (W) = AMOUNT OF CARGO TO BE LOADED/ OFFLOADED (TONS).
   (-1) = MAXIMUM AMOUNT OF CARGO WHICH CAN BE LOADED/ OFFLOADED IS TO BE CALCULATED BY THE PROGRAM.

3. VALUES GIVEN FOR ITEM 11 MEAN:
   (F) = FREIGHT RATE FOR CARGO OFFLOADED ($/TON).
   (-1) = RFR IS TO BE CALCULATED BY THE PROGRAM.

FIGURE A-3 (CONT.) - PROGRAM "GENEC" INPUT DATA FORMS

ITEM	DESCRIPTION	UNITS	QUANTITY
I	NAME OF COST		
1	AMOUNT	(NOTE 1)	
2	ESCALATION	%/YEAR	
3	MULTIPLYING FACTOR	(NOTES 2 & 4)	
4			
5	MULTIPLYING FACTOR	(NOTES 3 & 4)	
6			
7	MULTIPLYING FACTOR	(NOTES 3 & 4)	
8			
9	TIME OF PAYMENT	(NOTE 5)	
10			

NOTES

1. ITEM 1 MAY BE GIVEN IN "DOLLARS" OR IN ANY OTHER UNITS, DEPENDING ON THE MULTIPLYING FACTORS GIVEN IN ITEMS 3/4, 5/6, & 7/8.

2. VALUES GIVEN FOR ITEMS 3/4 MEAN:
   (-1,0) = DISTRIBUTE ITEM 1 UNIFORMLY OVER THE ENTIRE VOYAGE.
   (0,F) = MULTIPLY ITEM 1 BY (F).
   (J, I) = MULTIPLY ITEM 1 BY THE VALUE OF ACCOUNT (J) ITEM (I).

3. VALUES GIVEN FOR ITEMS 5/6 & 7/8 MEAN:
   (-1,F) = DIVIDE ITEM 1 BY (F).
   (0,F) = MULTIPLY ITEM 1 BY (F).
   (J,I) = MULTIPLY ITEM 1 BY THE VALUE OF ACCOUNT (J ITEM (I).

4. FACTORS 3/4, 5/6 & 7/8 ARE APPLIED SEQUENTIALLY – THAT IS:
   BASIC COST = (ITEM 1) * f(3/4) * f(5/6) * f(7/8).

5. VALUES GIVEN FOR ITEMS 9/10 MEAN:
   (1, M) = A SINGLE PAYMENT AT THE END OF (M) MONTHS AFTER CONTRACT.
   (2, M) = MULTIPLE PAYMENTS AT THE BEGINNING OF EACH (M) MONTH PERIOD FROM CONTRACT TO DELIVERY (FOR CAPITALIZED COSTS) OR FROM DELIVERY TO END – OF – LIFE (FOR OPERATING COSTS).
   (3,M) = MULTIPLE PAYMENTS AT THE END OF EACH (M) MONTH PERIOD FROM CONTRACT TO DELIVERY (FOR CAPITALIZED COSTS) OR FROM DELIVERY TO END – OF – LIFE (FOR OPERATING COSTS).
   (4, N) = (N) PAYMENTS MADE IN ACCORDANCE WITH TABLE A.

FIGURE A-3 (CONT.) - PROGRAM "GENEC" INPUT DATA FORMS

LINE	MONTH	%	LINE	MONTH	%	LINE	MONTH	%	LINE	MONTH	%
1			26			51			76		
2			27			52			77		
3			28			53			78		
4			29			54			79		
5			30			55			80		
6			31			56			81		
7			32			57			82		
8			33			58			83		
9			34			59			84		
10			35			60			85		
11			36			61			86		
12			37			62			87		
13			38			63			88		
14			39			64			89		
15			40			65			90		
16			41			66			91		
17			42			67			92		
18			43			68			93		
19			44			69			94		
20			45			70			95		
21			46			71			96		
22			47			72			97		
23			48			73			98		
24			49			74			99		
25			50			75			100		

NOTES

1. THIS TABLE FOLLOWS ITEM 10 OF THE CORRESPONDING COST ACCOUNT IT IS NOT TO BE USED UNLESS ITEM 9 OF THAT ACCOUNT IS 4.

2. ONLY (N) LINES OF TABLE A ARE TO BE USED. (N) IS THE VALUE GIVEN IN ITEM 10 OF THE ASSOCIATED COST ACCOUNT. (N<= 100)

3. "MONTH" IS THE MONTH AFTER CONTRACT FOR CAPITALIZED COSTS AND THE MONTH AFTER DELIVERY FOR OPERATING COSTS.

4. "%" IS THE PERCENT OF THE BASIC COST (SEE NOTE 4 OF THE COST ACCOUNT DATA SHEET) WHICH IS PAID AT THE END OF THE CORRESPONDING MONTH.

FIGURE A-3 (CONT.) - PROGRAM "GENEC" INPUT DATA FORMS

```
*LIST SAMPLE

1 "FILE SAVED AT 10.870 ON 05/30/78",
10 "SAMPLE PROBLEM",
11 2,2,8,9,75,
12 20,34,345,587653,30000,
13 100,1124,1533,25000,1,
14 5,
20 "RAS TANURA",
21 1.5,12200,14.2,127.68,287.04,
22 1,72.51,7.3,-1,0,
23 0,0,
30 "ROTTERDAM",
31 1.5,12200,15.28,127.68,287.04,
32 0,0,0,0,-1,
33 -1,0,
40 "ACQUIS.COST",224905000,8,0,.65,0,1,0,1,4,48,
41 28,.1,29,.2,30,.3,31,.5,32,.7,
42 33,.9,34,1,35,1.1,36,1.2,37,1.3,
43 38,1.4,39,1.4,40,1.4,41,1.5,42,1.6,
44 43,1.7,44,1.8,45,1.9,46,2,47,2.1,
45 48,2.2,49,2.3,50,2.4,51,2.4,52,2.4,
46 53,2.6,54,2.9,55,3.1,56,3.2,57,3.3,
47 58,3.4,59,3.5,60,3.7,61,3.9,62,3.8,
48 63,3.7,64,3.7,65,3.7,66,3.5,67,3.4,
49 68,3.2,69,2.8,70,2.2,71,1.8,72,1.4,73,.9,74,.4,75,.1,
50 "CONSTR.ADMIN.",6040,8,0,1,0,1,0,1,3,1,
60 "H&M INSUR.",1.125,0,4,1,-1,100,0,1,2,12,
70 "P&I INSUR.",1.25,0,1,9,0,1,0,1,2,12,
80 "MANNING",49200,8,1,7,-1,12,0,1,3,1,
90 "SUBSISTENCE",4.67,8,1,7,1,8,-1,12,3,1,
100 "STORES/SUPPLIES",200700,8,0,1,-1,12,0,1,3,1,
110 "ADMIN/MISC.",407900,8,0,1,-1,12,0,1,3,1,
120 "PORT CHARGES",136000,8,-1,0,0,1,0,1,3,1,
130 "MAINT/REPAIR",670000,8,0,1,-1,12,0,1,3,1,
```

FIGURE A-4 - SAMPLE DATA FILE LISTING

```
*RUN-10


DATA FILE ?SAMPLE
FILE SAVED AT 10.870 ON 05/30/78
NEW DATA       13.327          05/30/78
?0,0,0

OUTPUT ?3

SAMPLE PROBLEM
     DATA FILE: SAMPLE
     FILE SAVED AT 10.870 ON 05/30/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

RAS TANURA
DAYS IN PORT=  1.5
     FUEL CONSUMED=  191.52 TONS
NEXT LEG OF VOYAGE=   12200 MILES AT 14.2 KNOTS
     DAYS AT SEA=   35.79812
     FUEL CONSUMED=   10275.49 TONS
CARGO-OFFLOADED=    0 TONS
     -LOADED    =   564688.3 TONS
FUEL-LOADED=   20207.75 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      100 TONS
     FRESH WATER  =     1124 TONS
     BALLAST      =        0 TONS
     SERVICE FUEL =    20208 TONS
     RESERVE FUEL =     1533 TONS
     CARGO        =   564688 TONS
        TOTAL     =   587653 TONS
MAXIMUM DEADWEIGHT=  587653 TONS

ROTTERDAM
DAYS IN PORT=  1.5
     FUEL CONSUMED=  191.52 TONS
NEXT LEG OF VOYAGE=   12200 MILES AT   15.28 KNOTS
     DAYS AT SEA=   33.26789
     FUEL CONSUMED=   9549.215 TONS
CARGO-OFFLOADED=   564688.3 TONS
     -LOADED    =    0 TONS
FUEL-LOADED=    0 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      100 TONS
     FRESH WATER  =     1124 TONS
     BALLAST      =    17502 TONS
     SERVICE FUEL =     9741 TONS
     RESERVE FUEL =     1533 TONS
     CARGO        =        0 TONS
        TOTAL     =    30000 TONS
MAXIMUM DEADWEIGHT=  587653 TONS

TOTAL DAYS, ROUND TRIP=   72.06601
AVERAGE NUMBER OF TRIPS PER YEAR=   4.787278

OUTPUT ?STOP
```

FIGURE A-5 - PROGRAM "GENEC" OUTPUT - TYPE 3

```
*RUN-10


DATA FILE ?SAMPLE
FILE SAVED AT 10.870 ON 05/30/78
NEW DATA        13.354          05/30/78
?0,0,0

OUTPUT ?4

SAMPLE PROBLEM
     DATA FILE: SAMPLE
     FILE SAVED AT 10.870 ON 05/30/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< INCOME >>>>>
          PORT            TONS DELIV.    $/TON      ESCAL.    PRES.VAL.
                           PER YEAR                   %       ($1000)
     RAS TANURA                   0        .00       .00            0
     ROTTERDAM              2703319      18.07       .00       115375
          TOTAL             2703319                            115375

<<<<< EXPENSES >>>>>
          ITEM               AVG.ANN.   ESCAL.   % OF     PRES.VAL.     RFR
                             ($1000)     (%)     TOTAL    ($1000)       ($)
FUEL AT RAS TANURA             12936    7.30    26.48       30554      4.79
FUEL AT ROTTERDAM                  0     .00      .00           0       .00
ACQUIS.COST                    25272    8.00    51.74       59692      9.35
CONSTR.ADMIN.                     79    8.00      .16         187       .03
H&M INSUR.                      2650     .00     5.43        6260       .98
P&I INSUR.                       769     .00     1.58        1817       .28
MANNING                         3266    8.00     6.69        7714      1.21
SUBSISTENCE                      107    8.00      .22         253       .04
STORES/SUPPLIES                  392    8.00      .80         925       .14
ADMIN/MISC.                      796    8.00     1.63        1881       .29
PORT CHARGES                    1271    8.00     2.60        3002       .47
MAINT/REPAIR                    1308    8.00     2.68        3090       .48
          TOTAL                48846                       115375     18.07

CALCULATED RFR=    18.06895 $/TON AT DATE OF CONTRACT

OUTPUT ?STOP
```

FIGURE A-6 - PROGRAM "GENEC" OUTPUT - TYPE 4

```
*RUN-10

DATA FILE ?SAMPLE
FILE SAVED AT 10.870 ON 05/30/78
NEW DATA        13.873          05/30/78
?3,11,25
?0,0,0

OUTPUT ?4

SAMPLE PROBLEM
     DATA FILE: SAMPLE
     FILE SAVED AT 10.870 ON 05/30/78
     FILE MODIFIED AT 13.873 ON 05/30/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< INCOME >>>>>
          PORT            TONS DELIV.    $/TON      ESCAL.    PRES.VAL.
                           PER YEAR                   %       ($1000)
     RAS TANURA                   0        .00       .00            0
     ROTTERDAM              2703319      25.00       .00       159632
          TOTAL             2703319                            159632

<<<<< EXPENSES >>>>>
          ITEM               AVG.ANN.   ESCAL.   % OF     PRES.VAL.     RFR
                             ($1000)     (%)     TOTAL    ($1000)       ($)
FUEL AT RAS TANURA             12936    7.30    26.48       30554       .00
FUEL AT ROTTERDAM                  0     .00      .00           0       .00
ACQUIS.COST                    25272    8.00    51.74       59692       .00
CONSTR.ADMIN.                     79    8.00      .16         187       .00
H&M INSUR.                      2650     .00     5.43        6260       .00
P&I INSUR.                       769     .00     1.58        1817       .00
MANNING                         3266    8.00     6.69        7714       .00
SUBSISTENCE                      107    8.00      .22         253       .00
STORES/SUPPLIES                  392    8.00      .80         925       .00
ADMIN/MISC.                      796    8.00     1.63        1881       .00
PORT CHARGES                    1271    8.00     2.60        3002       .00
MAINT/REPAIR                    1308    8.00     2.68        3090       .00
          TOTAL                48846                       115375       .00

NET PRESENT VALUE=  44257000 $

OUTPUT ?STOP
```

FIGURE A-7 - PROGRAM "GENEC" OUTPUT - TYPE 4

```
*RUN-10


DATA FILE ?SAMPLE
FILE SAVED AT 10.870 ON 05/30/78
NEW DATA        8.242           05/31/78
?0,0,0

OUTPUT ?5

CALCULATED RFR=   18.06895 $/TON AT DATE OF CONTRACT

OUTPUT ?6

WHAT ACCOUNTS ?2,4,6,8,10
WHAT MONTHS ?73,88

SAMPLE PROBLEM
     DATA FILE: SAMPLE
     FILE SAVED AT 10.870 ON 05/30/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< COSTS BY MONTHS >>>>>
```

MONTH	RAS TANURA	ACQUIS.COST	H&M INSUR.	MANNING	STORES/SUPPL
73	0	2101275	0	0	0
74	0	939909	0	0	0
75	0	236489	2530181	0	0
*****FIRST MONTH OF OPERATING EXPENSES INCLUDED IN ANALYSIS					
76	913317	0	0	226959	27230
77	918695	0	0	228419	27405
78	924105	0	0	229888	27582
79	929547	0	0	231368	27759
80	935021	0	0	232856	27938
81	940527	0	0	234354	28117
82	946066	0	0	235862	28298
83	951637	0	0	237380	28480
84	957241	0	0	238907	28664
85	962878	0	0	240444	28848
86	968548	0	0	241991	29034
87	974252	0	2530181	243548	29221
88	979989	0	0	245115	29409

```
OUTPUT ?STOP
```

FIGURE A-8 - PROGRAM "GENEC" OUTPUT - TYPE 5 & 6

```
*RUN-10


DATA FILE ?SAMPLE
FILE SAVED AT 10.870 ON 05/30/78
NEW DATA        8.202           05/31/78
?0,0,0

OUTPUT ?5

CALCULATED RFR=   18.06895 $/TON AT DATE OF CONTRACT

OUTPUT ?2

FILE SAVED AT 10.870 ON 05/30/78
NEW DATA        8.209           05/31/78
?1,16,20
?0,0,0

OUTPUT ?5

CALCULATED RFR=   22.12586 $/TON AT DATE OF CONTRACT

OUTPUT ?1

DATA FILE ?SAMPLE
FILE SAVED AT 10.870 ON 05/30/78
NEW DATA        8.218           05/31/78
?0,0,0

OUTPUT ?5

CALCULATED RFR=   18.06895 $/TON AT DATE OF CONTRACT

OUTPUT ?STOP
```

FIGURE A-9 - PROGRAM "GENEC" OUTPUT -
ACCEPTING NEW DATA

which is attributable to each account and the amount of RFR which is attributable to each account. If RFR was calculated, it was established at a value which would make the present value of income equal to the present value of expenses. In this case, the fourth block gives RFR, as shown in Figure A6. If a freight rate was specified at every port where cargo was off-loaded, however, the present value of income will not necessarily equal the present value of expenses. The difference is Net Present Value. In this case, the fourth block gives NPV and RFR is set equal to zero, as shown in Figure A7.

Figure A8 shows the output identified as Type 5 and Type 6. Type 5 output is a single line which gives the calculated RFR at date of contract. Type 6 output contains three blocks of data. The first block identifies the account numbers and months for which output is desired. The second block identifies the data file used. The third block gives the actual cost for each specified account for each specified month. These costs include escalation but have not been "present valued." (In Figure A8 the account labeled "RAS TANURA" refers to fuel purchased at that port.)

There also are a number of program-generated messages which may appear with any of this output. These messages are described in the section on OPERATION, below.

OPERATION

Figures A5 through A9 illustrate the operation of this program. When the comand "RUN" is given, the computer will ask "DATA FILE?". The response is the name of a previously saved data file. The computer then prints a line of file identification (input data sheet page 1, item I), and a line of run identification: "NEW DATA (time)(date)." Next it asks for input by printing "?". The response is three numbers (X, Y, Z) separated by commas. The first of these numbers tells the computer what to do. This number has the following meanings:

X = 0: Execute program with current data

X > 0: Substitute Z for the number currently given on input data sheet X, item Y.

When X refers to a "cost" account and Y refers to item 9 of that account and Z is "4", the change will involve Table "A" of Figure A3. In this case the computer will ask "HOW MANY CHANGES?". The response is (W), the number of changes to Table "A". The computer will then ask for input (W) times. Each time the response is three numbers (A, B, C) separated by commas. These numbers have the following meanings:

A = Line number of Table "A"

B = "Month" for line (A)

C = "Percentage" for line (A)

The computer will continue to ask for data changes until it is directed to execute the program as described above (X = 0). It will then ask "OUTPUT?".

The response is a number from 1 to 6 with the following meanings:

1 = No output. The computer will print "DATA FILE?" and will accept the name of a new data file as shown in Figure A9.

2 = No output. The computer will print "NEW DATA (time)(date)" and will accept new data as shown in Figure A9.

3 = Print "Voyage Data" as shown in Figure A5.

4 = Print "Present Value Data" as shown in Figures A6 and A7.

5 = Print "RFR" as shown in Figure A8.

6 = Print "Costs by Months" as shown in Figure A8.

If output option "6" is selected, the computer will ask "WHAT ACCOUNTS?". The response is five numbers separated by commas. These are the numbers of the cost accounts to be printed. (If this number refers to a "port" account, the values printed will be the cost of fuel at that port. There is no cost account #1.) The computer will then ask "WHAT MONTHS?". The response is two numbers separated by a comma. These are the earliest and latest of the series of months (after contract) to be printed.

After the desired output has been printed, the computer will again ask "OUTPUT?" so that program execution can continue with as many data files, data changes and sets of output as needed. Any data changes which are input in response to the question "NEW DATA?" remain in the program for the duration of that run. Subsequent responses to this question may modify that data again, or may modify other data, but the original data are not restored unless the entire file is reloaded in response to the question "DATA FILE?".

When no further runs are desired, the response "STOP" wil terminate the program.

There are eight computer-generated information messages which may appear during program execution. These are:

1. "FILE MODIFIED AT (time) ON (date)"

This message appears as a fourth line in the block of output which identifies the data file used (output options "3", "4", and "6"). It appears when changes have been made to that data file during program execution.

2. "SHIP CAN ONLY LOAD (xxx) TONS OF FUEL AT (port)"

This message appears when the amount of fuel specified by the input data file to be loaded at this port, plus the fuel already on board, is greater than the capacity of the F.O. tanks. The program continues with the reduced amount of fuel on board.

3. "SHIP MUST LOAD (xxx) TONS OF FUEL AT (port)"

This message appears when the amount of service fuel on board is less than the amount needed to reach the next port and operate the ship during its stay in that port, and the input data file does not call for fuel to be loaded. The program continues with the increased amount of fuel on board.

4. "OUT OF FUEL AFTER (port)"

This message appears when the amount of service fuel on board (with all F.O. tanks full) is not sufficient to reach the next port. This message terminates execution of the run; the computer will ask "NEW DATA (time)(date)?" and will accept the data modification needed.

5. "NO COST DATA FOR FUEL AT (port)"

This message appears when fuel is loaded at a port but the input data file does not include cost data for that fuel. This message terminates execution of the run; the computer will ask "NEW DATA (time)(date?" and will accept the data modification needed.

6. "SHIP CAN ONLY OFF LOAD (xxx) TONS OF CARGO AT (port)"

This message appears when the input data file specifies an amount of cargo to be off-loaded which is greater than the amount of cargo on board. The program continues with the reduced amount of cargo off loaded.

7. "SHIP CAN ONLY LOAD (xxx) TONS OF CARGO AT (port)"

This message appears when the input data file specifies an amount of cargo to be loaded which would make the total deadweight on board (crew and stores, fresh water, service fuel, reserve fuel and cargo) greater than the maximum allowable deadweight. The program continues with the reduced amount of cargo loaded.

8. "TOO MANY IRREGULAR PAYMENT SCHEDULES"

This message appears when the input data file has more than 5 accounts with irregular payment schedules (input data sheet item 9 = 4, which requires the use of Table "A"). Currently the program dimension statements provide storage for no more than five sets of Table "A" variables. This message terminates execution of the run; the computer will ask "DATA FILE?" and will accept the name of a new data file as described above.

APPENDIX B

NON-ECONOMIC EVALUATION DESCRIPTION

CONTENTS

APPENDIX B - CONTENTS (CONT.)

EVALUATION OF NON-ECONOMIC FACTORS

Figures B1 through B5 can be used to calculate ratings for the five non-economic factors currently identified in the Material Trade-Off Study. These factors and their attributes are discussed below. Other factors and attributes can be used by any shipowner to suit his specific needs.

Many of these factors and attributes may affect costs. In every case, the identifiable dollar cost associated with such an attribute must be included in the economic evaluation of Appendix A. The non-economic evaluation is limited to a subjective consideration of cost trends where the dollar amount cannot be determined, and to a consideration of attributes which are not directly associated with costs.

I. SUITABILITY FOR INTENDED USE

A. Susceptibility to Damage

This attribute is subdivided into four types of damage:

- Mechanical
- Chemical
- Thermal
- Corrosion

1. Mechanical damage includes the susceptibility to tearing, buckling, denting or abrasion from such things as grounding, collision, internal or external explosions, missiles, cargo and cargo handling apparatus, tugboats, piers, etc.

2. Chemical damage includes the susceptibility to adverse chemical reaction with solids, liquids or vapors. The source of these reagents may be on the ship (such things as cleaning solutions or preservatives) or off the ship (such things as fumes from chemical plants near the pier, or industrial wastes). This category does not include the effect of chemical cargoes (that is in Attribute D).

3. Thermal damage includes the susceptibility to material degradation from temperature extremes or from the effects of expansion and contraction. This category includes the effect of cold weather on material properties, but not the mechanical effect of ice on the structure (that is in Part 1, Mechanical Damage). It includes the effects of fires off the ship and of long-lasting fires on the ship (neither of these is included in the current rules for structural fire protection).

4. Corrosion damage includes the susceptibility to structural degradation from wastage under normal operating conditions, and to the adverse effects of corrosion products. Wastage includes the normal overall corrosion of material exposed to bilge or salt water or salt air, as well as to the

BY ______________________ DATE ______________

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
SUSCEPTABILITY TO DAMAGE – MECHANICAL							
– CHEMICAL							
– THERMAL							
– CORROSION							
POTENTIAL EFFECTS OF DAMAGE							
AVAILABILITY OF REPAIR FACILITIES							
COMPATIBILITY WITH INTENDED CARGO							
COMPATIBILITY WITH INTENDED OPERATING LOCATION							
HYDRODYNAMIC CHARACTERISTICS							
APPEARANCE							
TOTAL							
FACTOR RATINGS							

$$\text{RATINGS FOR THIS FACTOR} = \frac{\sum \text{WEIGHTED VALUES}}{10 \cdot \sum \text{WEIGHTS}}$$

FIGURE B-1 – MATERIAL TRADE-OFF STUDY – EVALUATION OF NON-ECONOMIC FACTORS SUITABILITY FOR INTENDED USE

BY ______________________ DATE ______________

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.		WTD. VAL.
EFFECT ON LAND – DURING PRODUCTION OF RAW MATERIALS							
– DURING CONSTRUCTION/REPAIR/SCRAPPING							
– DURING OPERATIONS							
EFFECT ON WATER – DURING PRODUCTION OF RAW MATERIALS							
– DURING CONSTRUCTION/REPAIR/SCRAPPING							
– DURING OPERATIONS							
EFFECT ON AIR – DURING PRODUCTION OF RAW MATERIALS							
– DURING CONSTRUCTION/REPAIR/SCRAPPING							
– DURING OPERATIONS							
EFFECT ON WILDLIFE – DURING PRODUCTION OF RAW MATERIALS							
– DURING CONSTRUCTION/REPAIR/SCRAPPING							
– DURING OPERATIONS							
EFFECT ON PEOPLE – DURING PRODUCTION OF RAW MATERIALS							
– DURING CONSTRUCTION/REPAIR/SCRAPPING							
– DURING OPERATIONS							
TOTAL							
FACTOR RATINGS							

$$\text{RATING FOR THIS FACTOR} = \frac{\Sigma \text{ WEIGHTED VALUES}}{10 \cdot \Sigma \text{ WEIGHTS}}$$

FIGURE B-2 - MATERIAL TRADE-OFF STUDY - EVALUATION OF NON-ECONOMIC FACTORS ENVIRONMENTAL IMPACT

BY ______________________ DATE ______________

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
MATERIALS							
ENERGY							
MANPOWER – SKILLED							
– UNSKILLED							
PRODUCTION FACILITIES							
TRANSPORTATION FACILITIES							
BALANCE OF TRADE (IMPORT/EXPORT)							
TOTAL							
FACTOR RATINGS							

RATING FOR THIS FACTOR = $\dfrac{\Sigma \text{ WEIGHTED VALUES}}{10 * \Sigma \text{ WEIGHTS}}$

FIGURE B-3 - MATERIAL TRADE-OFF STUDY - EVALUATION OF NON-ECONOMIC FACTORS
USE OF NATIONAL RESOURCES

BY ______________________ DATE ______________

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
DEVELOPMENT OF RULES/REGULATIONS							
DEVELOPMENT OF INTERNATIONAL AGREEMENTS							
SUBSIDY – CONSTRUCTION							
– OPERATING							
LOAN GUARANTEES							
INSURANCE (IF NOT AVAILABLE COMMERCIALLY)							
TOTAL							
FACTOR RATINGS							

$$\text{RATING FOR THIS FACTOR} = \frac{\sum \text{WEIGHTED VALUES}}{10 * \sum \text{WEIGHTS}}$$

FIGURE B-4 - MATERIAL TRADE-OFF STUDY - EVALUATION OF NON-ECONPMIC FACTORS GOVERNMENT INVOLVEMENT

BY ______________________________ DATE ____________________

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
TECHNICAL – UNFORESEEN PROBLEMS IN DESIGN							
– UNFORESEEN PROBLEMS IN CONSTRUCTION							
– UNFORESEEN PROBLEMS IN MAINTENANCE/REPAIR							
– UNFORESEEN PROBLEMS IN OPERATION							
FINANCIAL – CHANGES IN CONSTRUCTION COST ESTIMATES							
– CHANGES IN MAINTENANCE/REPAIR COST ESTIMATES							
– CHANGES IN OPERATING COST ESTIMATES							
– CHANGES IN FINANCING/INSURANCE COST ESTIMATES							
REGULATORY – UNFORESEEN CHANGES IN REQUIREMENTS							
– LIMITATIONS ON HARBOR ENTRY							
AVAILABILITY OF CREW							
SUITABILITY FOR ALTERNATE CARGOES							
SUITABILITY FOR ALTERNATE OPERATING LOCATIONS							
TOTAL							
FACTOR RATINGS							

$$\text{RATING FOR THIS FACTOR} = \frac{\sum \text{WEIGHTED VALUES}}{10 * \sum \text{WEIGHTS}}$$

FIGURE B-5 - MATERIAL TRADE-OFF STUDY - EVALUATION OF NON-ECONOMIC FACTORS RISK pitting or localized corrosion caused by galvanic action set up by stray electric currents or by contact between dissimilar metals. Dissimilar materials may be part of the ship or may be such things as steel piers, metal hawsers, etc. Corrosion products may be unsightly, may be toxic, may tend to spread under protective coatings, may rub off on nearby materials, etc. This category does not include the effect of cargo-induced corrosion (that is in Attribute D).

B. Potential Effects of Damage

This attribute measures the potential danger associated with the damages of Attribute A. Except for a few cases of brittle failure, steel ships usually resist damage quite well. Deterioration is gradual and predictable, allowing ample time for repair. This may not be true for other materials. The initial damage may be so widespread, or so concealed, or may spread so rapidly, as to cause extensive secondary damages to the cargo or to the ship itself.

C. Availability of Repair Facilities

This attribute measures the ease and rapidity with which the damages of Attribute A can be fixed. Even minor damage can be crippling if the ship must travel half-way around the world to get to a repair yard.

D. Compatibility with Intended Cargo

This attribute measures the suitability of a selected structural material for use with the intended cargo. It includes such things as contamination of the cargo by the material, or chemical attack on the material by the cargo, or cargo-induced corrosion of the structure. It does not include mechanical damage by the cargo or cargo handling equipment (that is in Attribute A).

E. Compatibility with Intended Operating Location

This attribute measures the suitability of a selected structural material for use on the intended service route. Different service routes expose the ship to different conditions and hazards. A material (wood for example) may be very useful for some locations (such as arctic service) and be unsuited for other locations (such as tropical service where wood-borers are prevalent).

F. Hydrodynamic Characteristics

This attribute measures the effect of a selected structural material on the hydrodynamic performance of the proposed ship. Items to be considered are the ability of the material to be shaped to the desired molded form, its ability to maintain that shape in service, its surface roughness characteristics, and its susceptibility to fouling.

G. Appearance

This attribute measures the ability of a selected material to attain and retain an appearance which is suitable for the type of ship. Obviously a yacht or passenger ship has very different appearance requirements from a work boat or barge.

II. ENVIRONMENTAL IMPACT

Each of the five attributes affecting Environmental Impact is subdivided into three eras because the problems are different in each era. The subdivisions are:

- production of raw materials
- construction/repair/scrapping
- operations

A. Effect on Land

This attribute measures the effect of a selected material on the land. It includes consideration of such things as land clearing, strip mining, construction of roads and facilities, erosion, etc.

B. Effect on Water

This attribute measures the effect of a selected material on water quality. It includes such things as the contribution toward flooding or toward a lack of water, obstruction of streams or waterways, dredging, waste pollution of water, etc.

C. Effect on Air

This attribute measures the effect of a selected material on air quality. It includes such things as smoke, dust and smog pollution of the atmosphere, creation of toxic or noxious gases, etc.

D. Effect on Wildlife

This attribute measures the effect of a selected material on plants, animals, birds, and fishes. It includes such things as destruction of wildlife itself, changes to the habitat and environment of the wildlife, changes to the feeding and migratory patterns of the wildlife, etc.

E. Effect on People

This attribute measures the effect of a selected material on people. It includes such things as the impact of noise, light, vibration, odors, appearance, etc. on the safety, comfort and happiness of the workers and the people in surrounding communities.

III. USE OF NATIONAL RESOURCES

A. Materials

This attribute measures the impact of a selected material on the world supply of materials. A material which is readily available, either as unmined ore or as scrap, is preferable to one which is in short supply or is maintained in the National Defense Stockpile. This category does not include the effect of buying material from foreign sources (that is in Attribute F).

B. Energy

This attribute measures the impact of a selected material on the consumption of energy. Use of energy from replaceable sources, such as waterpower, or a reduced use of energy, is preferable to the use of irreplaceable sources such as petroleum.

C. Manpower

This attribute is subdivided into two parts:

- skilled labor
- unskilled labor

When a labor shortage exists, it is advantageous to use a material with low manpower requirements. When there is a high unemployment rate, however, it may be preferable to use a material with higher manpower requirements. This attribute is subdivided to permit separate consideration of the labor markets for skilled and unskilled workers.

D. Production Facilities

This attribute measures the impact of a selected material on the use of production facilities. When these facilities are busy, it is advantageous to use a material which minimizes the additional workload. If, however, the facilities are not otherwise used, this workload should have little effect unless it becomes the only way to keep a production facility active.

E. Transportation Facilities

This attribute measures the impact of a selected material on the use of transportation facilities. In general, it is preferable to avoid the use of transportation facilities, particularly when they are needed for other purposes.

F. Balance of Trade

This attribute measures the impact of a selected material on the national balance of trade. Any materials or services which must be purchased from a foreign source have an adverse effect on the balance of trade. In some cases, however, funds may be "frozen" in a foreign country and such imports can be the only way to recover this money.

IV. GOVERNMENT INVOLVEMENT

A. Development of Rules and Regulations

Use of a new material may require the development of new rules and regulations, or the modification of existing requirements. In either case the rule making process is apt to be time-consuming and expensive, both to the agencies involved and to the prospective user. Such indirect costs would reduce the worth of the proposed ship. Areas to be considered as candidates for new rules include:

- structural fire protection
- fire fighting equipment
- lifesaving equipment
- public health requirements
- OSHA requirements
- electrical safety requirements
- inspection and overhaul requirements

B. Development of International Agreements

In addition to the regulations of U.S. agencies, a shipowner is subject to the regulations of foreign governments and to international treaties such as SOLAS. These international requirements may be harder to modify than the U.S. requirements described in Attribute A.

C. Subsidy

Many ships are eligible for two types of governmental subsidy:

- construction
- operation

D. Loan Guarantees

Another form of government participation in the shipbuilding and shipping industry is the guarantees of construction loans. Any change in material which affects these guarantees will have an effect on the worth of the proposed ship.

E. Insurance

Insurance is normally handled by commercial underwriters. If, however, a new material is such that suitable insurance cannot be obtained commercially, the government would be called upon to act as an underwriter. Such a contingency would affect the worth of a proposed ship.

V. RISK

A. Technical

This attribute is a measure of the likelihood that a selected material will not perform as well as predicted, or that it will require more time for construction, overhaul or repair than was allotted in the economic analysis.

Either of these contingencies will reduce the worth of the proposed ship.

Technical risk is subdivided into the risk of unforeseen problems in:

- o design
- o construction
- o maintenance and repair
- o operation

B. Financial

This attribute is a measure of the likelihood that cost estimates used for economic analysis of the proposed ship contain significant errors. Such errors can either increase or decrease the worth of the proposed ship, but only the potential decrease is considered a risk.

Financial risk is subdivided into changes in the cost estimates for:

- o construction
- o maintenance and repair
- o operation
- o financing and insurance

C. Regulatory

This attribute is a measure of the likelihood that future governmental action will change the rules under which the ship design was made. Such changes can either increase or decrease the worth of the proposed ship, but only the potential decrease is considered a risk.

Regulatory risk is subdivided into two parts:

- o unforeseen changes in requirements
- o limitations on harbor entry

D. Availability of Crew

This attribute is a measure of the likelihood that use of a selected material will require an unforeseen increase in crew costs. Such an increase may be required by union demands for a larger crew, for a higher pay scale, or for improved subsistence and habitability.

E. Suitability for Alternate Cargoes

A ship which is limited to handling one type of cargo may be worth less than a ship which can handle many cargoes. If the availability of the specialized cargo should be reduced, the single-purpose ship would require lay-up or expensive modification, whereas the multi-purpose ship could carry other cargoes. This attribute is a measure of that risk.

F. Suitability for Alternate Operating Locations

A ship which is limited to one trade route may be worth less than a ship which can travel many routes. If the availability of cargoes on the single trade route should be reduced, the single-purpose ship would require lay-up or expensive modification, whereas the multi-purpose ship could move to a different route. This attribute is a measure of that risk.

APPENDIX C

SAMPLE DATA BANK

CONTENTS

PART IA

MATERIAL PROPERTIES - ABS MILD STEEL

1. MATERIAL: ABS Mild Steel

   Six Grades: A, B, D, E, DS, CS

   Grade to be used depends on location in hull and thickness required (see ABS rules section 43.3.8).

2. SUITABILITY FOR MARINE ENVIRONMENT:

   2.1 OPERATIONAL EXPERIENCE: most widely used commercial structural material.

   2.2 ADVANTAGES:

   2.2.1 Relatively low cost
   2.2.2 Relatively easy to fabricate
   2.2.3 Fire resistant
   2.2.4 Welds can develop the full strength of the base material

   2.3 DISADVANTAGES:

   2.3.1 Low corrosion resistance - must be protected
   2.3.2 Susceptible to brittle fracture at low temperatures
   2.3.3 High density

   2.4 AVAILABILITY: Typical lead time 2 months

   2.5 COST: Mid 1977 - material, large quantities plates or shapes - 19¢/#

   2.6 SCRAP VALUE: Mid 1977 - 4 ¢/#

3. DESIGN PROPERTIES:

3.1	Design Yield Strength	34,000 psi
3.2	Design Ultimate Strength	58,000 psi
3.3	Modulus of Elasticity	29 x 10^6 psi
3.4	Shear Modulus	11 x 10^6 psi
3.5	Poisson's Ratio	0.3
3.6	Density	0.283 lbs/in^3
3.7	Typical Size or Thickness Limitations	Specially approved specifications required for thickness over 2.0 inches

4. FABRICABILITY:

4.1 JOINING: Readily welded with a variety of manual and automatic processes. Welds develop the full strength of the base material. Welder qualification tests per ABS.

- 4.1.1 Mechanical fastening - riveting and bolting are readily performed but superseded by welding for hull structures.
- 4.1.2 Dissimilar metal joining - cladding, buttering, welding, explosive bonding.
- 4.1.3 Brazing - readily performed.
- 4.1.4 Shielded metal arc weld (SMAW) - readily performed.
- 4.1.5 Submerged arc weld (SAW) - readily performed
- 4.1.6 Electroslag weld (ESW - readily performed - vertical position - heavy plates
- 4.1.7 Electrogas weld (EGW) - readily performed - vertical position
- 4.1.8 Gas-tungsten arc weld (GTAW) - readily performed
- 4.1.9 Gas-metal arc weld (GMAW) = readily performed
- 4.1.10 Electron beam weld (EBW) - can be performed
- 4.1.11 Resistance weld (RW) - can be performed
- 4.1.12 Adhesive bonding - not applicable to hull plate thicknesses

4.2 FORMING: readily formed

4.3 MACHINING: readily machined

4.4 THERMAL TREATMENT:

Grades D and DS over 1.375 inches thick are normalized
Grades E and CS are normalized

4.5 DISTORTION CONTROL:

- 4.5.1 Peening to correct distortion or to reduce residual stresses is permissible.
- 4.5.2 Fairing by heating or flame shrinking or other methods is permissible. For main strength members within the midships portion and other highly stressed plating, ABS surveyor approval is required.

5. NONDESTRUCTIVE TESTING/QUALITY CONTROL:

- 5.1 Liquid Penetrant - extensive experience
- 5.2 Magnetic Particle - extensive experience
- 5.3 Radiography - extensive experience
- 5.4 Ultrasonics - extensive experience
- 5.5 Acoustical Emission - no information

6. MAINTENANCE AND REPAIR:

6.1 Coatings are required both above and below the waterline to reduce corrosion. In addition, a corrosion allowance in the form of added material is provided for all exposed plating and framing. When special protective coatings are used, the scantlings of longitudinal strength structure may be reduced by 10% or 0.125 inch maximum.

6.2 This material is relatively eacy to repair in the field or in a shipyard. No post-weld heat treatment is required.

7. PHYSICAL AND CHEMICAL PROPERTIES:

7.1 COMPOSITION (Typical values - some variations permitted in special cases):

Grade	A	B	D	E	DS	CS
Deoxidation	any method except rimmed steel	any method except rimmed steel	fully killed, fine-grain practice	fully killed, fine-grain practice	fully killed, fine-grain practice	fully killed, fine-grain practice
Carbon-max%	0.23	0.21	0.21	0.18	0.16	0.16
Manganese-%		0.80-1.10	0.70-1.40	0.70-1.50	1.00-1.35	1.00-1.35
Phosphorous-max%	0.04	0.04	0.04	0.04	0.04	0.04
Sulphur-max %	0.04	0.04	0.04	0.04	0.04	0.04
Silicon-%	N/A	0.35 max	0.10-0.35	0.10-0.35	0.10-0.35	0.10-0.35

7.2 CORROSION:

7.2.1	General with water flow < 10 fps,	4-6 mils per year up to 50 mils per year in splash zone if unprotected
	with water flow rate > 10 fps	(not available)
7.2.2	Pitting and crevice	minor
7.2.3	Stress	none
7.2.4	Cavitation	moderate
7.2.5	Fouling	poor resistance
7.2.6	H_2 Embrittlement	none
7.2.7	Exfoliation	none

7.2.8 Cargo Compatibility — Compatible with most large volume dry and liquid bulk cargo. Various chemicals are corrosive to mild steel but stainless steel cladding and various protective coating systems are available.

7.3 EROSION: moderate

7.4 PROTECTION:

7.4.1 Coatings - required for protection from oxidation and to reduce fouling. Many types of coating systems available.
7.4.2 Anodes - zinc or aluminum
7.4.3 Cathodic protection system - available

7.5 THERMAL CONDUCTIVITY: 0.12 cal-cm/cm^2-°C-sec

7.6 COEFFICIENT OF THERMAL EXPANSION: 6.3./10^6 in/in °F

8. MECHANICAL PROPERTIES:

8.1	Yield Strength:	34.0 ksi min except for grade A over 1.00 inches which is 32.0 ksi min.
8.2	Tensile Strength;	58.0 - 71.0 ksi
8.3	Elongation:	24% min in 2 inches
8.4	Toughness:	

8.4.1 Charpy - Grade D - longitudinal - 20 ft-lbs at -4°F
transverse - 14 ft-lbs at -4°F

8.4.2	Dynamic tear 1"	(not available)
8.4.3	Dynamic tear 5/8"	(not available)
8.4.4	Kic	(not available)
8.4.5	Kiscc	(not available)

8.4.6 Nil ductibility temperature - Grade G - -20°F to + 40°F

8.5 HARDNESS: 110 - 140 BHN

8.6 FATIGUE STRENGTH: See Figure IA-8.6-1

8.7 CREEP:

8.7.1	Room temperature	(not available)
8.7.2	150°F	(not available)

9. MISCELLANEOUS:

9.1 SPECIFICATIONS: ABS
9.2 SPECIAL PROPERTIES: (not applicable)
9.3 REMARKS: (not applicable)

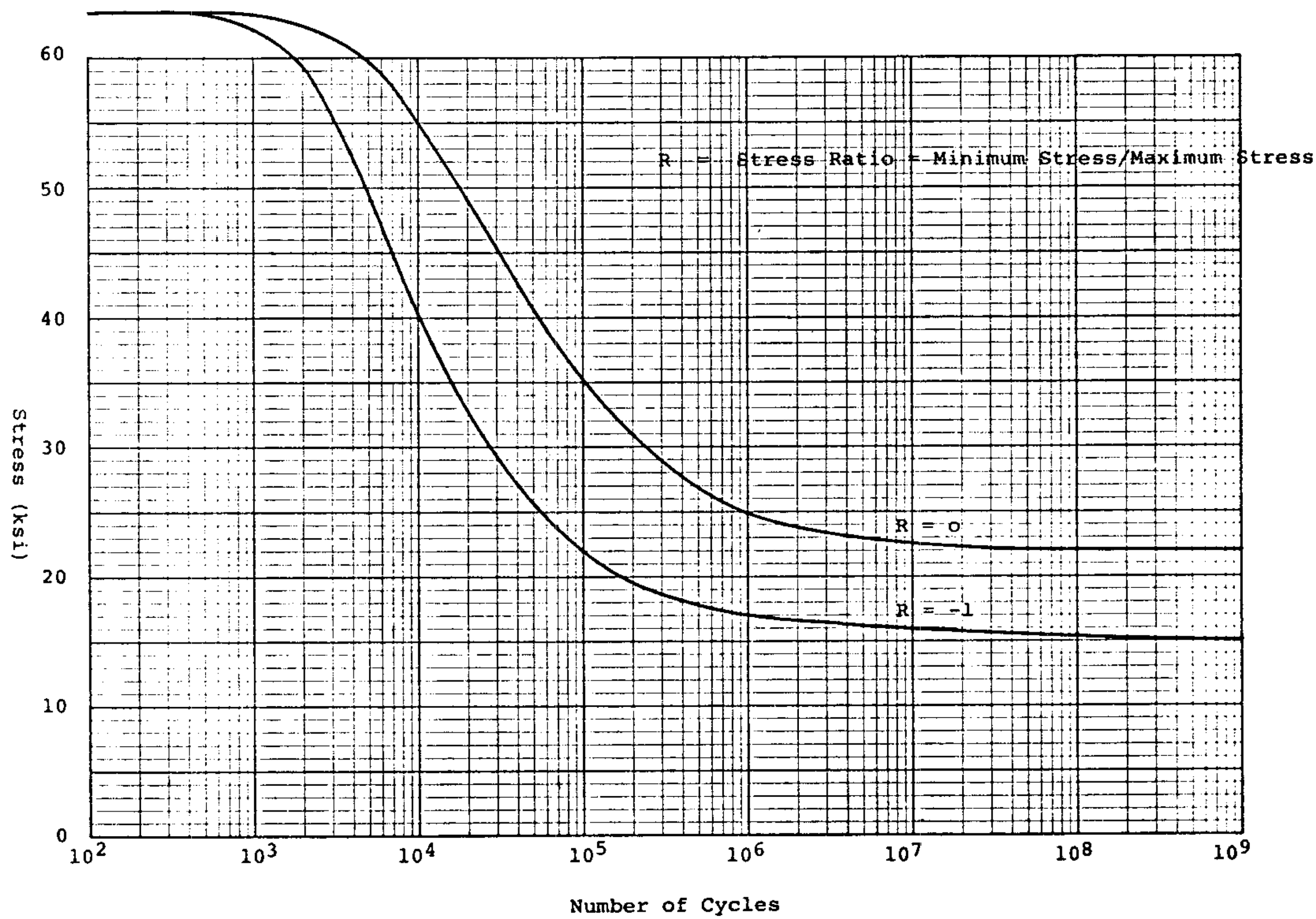


FIGURE C-1 - FATIGUE STRENGTH OF BUTT WELDED ABS MILD STEEL, BEAD ON

PART IB

MATERIAL PROPERTIES - 5456 ALUMINUM

1. MATERIAL: 5456 Aluminum

Sheet and plat temper:	H112, H116, H117, H323, H343
Extrusion tempers:	H111, H112
Die forgings:	H112
Hand forgings:	H112

2. SUITABILITY FOR MARINE ENVIRONMENT:

2.1 OPERATIONAL EXPERIENCE:

2.1.1 H116/H117 temper used for hulls on PHM, Boeing JETFOIL, and ALCOA/SEAPROBE.

2.1.2 H111 temper extrusion used for decking on PHM, Boeing JETFOIL, and ALCOA SEAPROBE.

2.1.3 H321 temper used extensively on Navy craft including USS HIGHPOINT, USS TUCUMCARI, and USS FLAGSTAFF. Considerable problems have been experienced with exfoliation. Some reported stress corrosion cracking on TUCUMCARI. Should not be used for hulls.

2.2 ADVANTAGES:

2.2.1 Low density

2.2.2 Resistant to exfoliation except in H321 temper.

2.3 DISADVANTAGES:

2.3.1 Low corrosion fatigue strength

2.3.2 High weld distortion peculiar to aluminum

2.3.3 Cannot be used where service temperature exceeds 150°F

2.3.4 Anodic to most structural materials. Protection system recommended

2.3.5 Welds cannot develop the full strength of the base material.

2.4 AVAILABILITY:

Delivery schedule uncertain. Typical lead time is 2 months.

2.5 COST: Mid 1977 - material, large quantities, plates or extrusions - 78 ¢/# (4.11)*

* Values in parenthesis are relationship to ABS mild steel.

2.6 SCRAP VALUE: Mid 1977 - 29 ¢/# (7.25)

3. DESIGN PROPERTIES (welded - all tempers):

3.1	DESIGN YIELD STRENGTH	19,000 psi (0.559)
3.2	DESIGN ULTIMATE STRENGTH	41,000 psi (0.707)
3.3	MODULUS OF ELASTICITY	10.3×10^6 psi (0.355)
3.4	SHEAR MODULUS	3.85×10^6 psi (0.350)
3.5	POISSON's RATIO	0.33
3.6	DENSITY	0.096 lbs/in^3 (0.339)
3.7	TYPICAL SIZE OF THICKNESS LIMITATIONS	up to 3.0 inches thickness

4. FABRICABILITY:

4.1 JOINING: Both manual and automatic welding have the same effect on strength but automatic welding produces more consistent results. Weld position has little effect on strength although providing access for the typical welding gun is sometimes difficult. Recommended filler wire is 5556. Welder qualification tests per ABS.

4.1.1 Mechanical fastening - rivet alloys 1100, 6054-T6, and 6053-T6.

4.1.2 Dissimilar metal joining - cladding, dip coating, electroplating, buttering, welding explosive bonding.

4.1.3 Brazing - difficult to braze - poor wetting - loss of properties

4.1.4 Shielded metal arc weld (SMAW) - not applicable

5. NONDESTRUCTIVE TESTING/QUALITY CONTROL:

5.1 LIQUID PENETRANT - extensive experience

5.2 MAGNETIC PARTICLE - not applicable

5.3 RADIOGRAPHY - extensive experience

5.4 ULTRASONICS - extensive experience

5.5 ACOUSTICAL EMISSION - limited experience

6. MAINTENANCE AND REPAIR:

6.1 Above the waterline relatively little maintenance is required. In many cases, the aluminum is left unpainted and needs only an occasional fresh water washdown. However, if painted for aesthetic or other reasons, the coating should be carefully maintained to prevent concentrated local corrosive or electrolytic attack at local breaks in the coating.

6.2 Below the waterline, primer and tributyl tin oxide antifouling paint or other coatings not containing copper, lead, or mercury are generally used.

6.3 When making weld repairs, some protection from wind is generally required. The filler wire must be stored in moisture free areas. No post weld heat treatment is required.

7. PHYSICAL AND CHEMICAL PROPERTIES:

7.1 COMPOSITION:

Magnesium	4.7-5.5	Zinc	0.25 max
Manganese	0.5-1.0	Titanium	0.20 max
Chromium	0.05-0.25	Others:	
Copper	0.1 max	Each	0.05 max
Silicon & Iron	0.4 max	Total	0.15 max

7.2 CORROSION:

7.2.1 General

with water flow rate < 10 fps	light - uniform
with water flow rate > 10 fps	(not available)

7.2.2	Pitting & Crevice	0.13-0.26 mpy	some pitting in splash zone
7.2.3	Stress	Good resistance	can occur under certain conditions - high temperatures - severe cold forming
7.2.4	Cavitation	Poor resistance	
7.2.5	Fouling	Poor resistance	
7.2.6	H_2 Embrittlement	none	
7.2.7	Exfoliation		none in H116/H117 temper - will occur in H321 temper
7.2.8	Cargo Compatibility		contact with copper, tin, or mercury ores, potassium carbonate, potassium hydroxide and trisodium phosphate should be avoided. Moisture in cargo holds should be minimized and the holds should be cleaned regularly to minimize cargo buildup when carrying ferrous ores, lime, aluminum floride, and aluminum sulphate.

7.3 EROSION: Poor resistance - will abrade at approximately 4 to 5 times the rate of mild steel.

7.4 PROTECTION:

7.4.1 Coatings - see item 6.1 and 6.2

7.4.2 Anodes - zinc or aluminum

7.4.3 Cathodic protection system - over protection is a severe problem - current demands on system are small at low velocity.

7.4.4 Fire - alternate procedures are available to ensure that aluminum structure provides protection "equivalent to steel" (see reference 23).

7.5 THERMAL CONDUCTIVITY: 0.28 cal-cm/cm^2-°C-sec (2.33)

7.6 COEFFICIENT OF THERMAL EXPANSION: 12.7/10^6 in/in-°F @ 68°F (2.02

8. MECHANICAL PROPERTIES:

Form	Temper	Thickness (inches)	8.1 *YIELD STRENGTH* minimum, 02% offset (ksi)	8.2 *ULTIMATE STRENGTH* minimum (ksi)	8.3 *ELONGATION* minimum in 2 inches (percent)
Butt Welded	All	to 1.5	19.0	41.0	
Sheet and Plate	0	0.051-1.500	19.0	42.0	16
		1.501-3.000	18.0	41.0	16
	H112	0.250-1.500	19.0	42.0	12
		1.501-3.000	18.0	41.0	12
	H116 & H117	0.063-0.624	33.0	46.0	12
		0.625-1.250	33.0	46.0	12
		1.251-1.500	31.0	44.0	12
		1.501-3.000	29.0	41.0	12
	H323	0.051-0.125	36.0	48.0	6
		0.126-0.249	36.0	48.0	8
	H343	0.051-0.125	41.0	53.0	6
		0.126-0.249	41.0	53.0	8
Extruded	0	to 5.0, 32 in^2 max area	19.0	41.0	14
	H111	to 5.0, 32 in^2 max area	26.0	42.0	12
	H112	to 5.0, 32 in^2 max area	19.0	41.0	12
Die forged	H112	to 4.0, parallel to grain flow	20.0	44.0	16
Hand forged	H112	to 3.0, longitudinal	20.0	44.0	16
		to 3.0 long transv.	18.0	42.0	14

8.4 TOUGHNESS:

8.4.1	Charpy	(not available)
8.4.2	Dynamic tear 1"	(not available)
8.4.3	Dynamic tear 5/8"	(not available)
8.4.4	K_{IC}	(not available)
8.4.5	K_{ISCC}	(not available)
8.4.6	Nil ductility temperature	(not applicable)

8.5 HARDNESS: annealed plate - 70 BHN

8.6 FATIGUE STRENGTH: See Figure IB-7.6-1

Strength of H321 temper at a given number of cycles varies from 0.45 to 0.74 that of ABS mild steel.

8.7 CREEP:

8.7.1	Room temperature	(not available)
8.7.2	150°F	(not available)

9. MISCELLANEOUS:

9.1 SPECIFICATIONS: ABS

9.2 SPECIAL PROPERTIES: nonmagnetic

9.3 REMARKS: (not applicable)

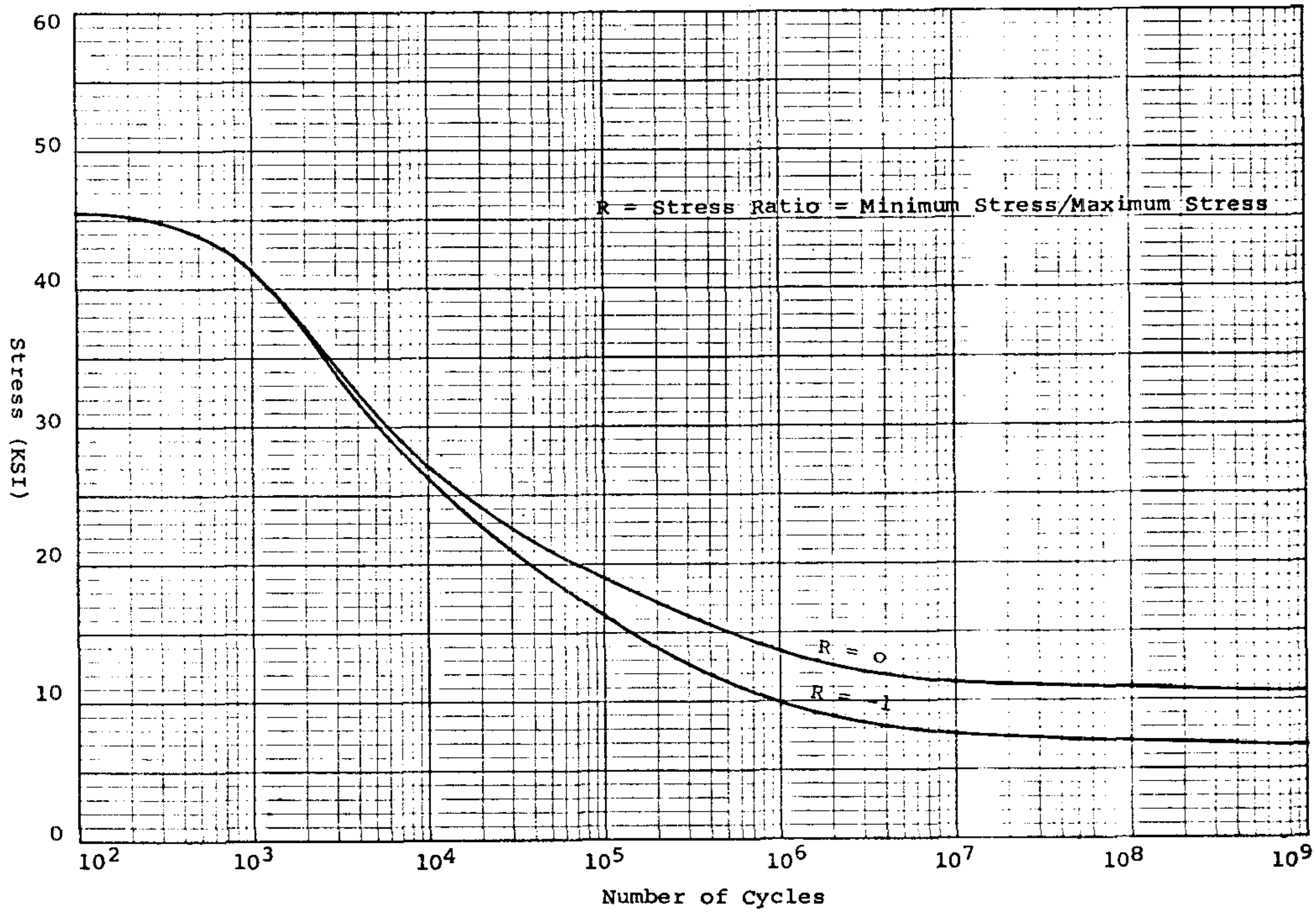


FIGURE C-2 - FATIGUE STRENGTH OF BUTT WELDED 5083-H113, BEAD ON

MATERIAL DATA BANK

PART II

5456 ALUMINUM

MATERIAL CONVERSION RELATIONSHIPS

Steel and aluminum are both homogeneous isotropic materials and, therefore, it is reasonable to assume that the stiffening systems will be similar. The optimum spacing of stiffeners for minimum weight or minimum fabricated cost for the two materials may be slightly different. For the purposes of this sample study, it should be sufficiently accurate to assume the same stiffener spacings and beam lengths for the aluminum ship as for the steel ship.

Material conversion factors must account for differences in material ultimate strength, yield strength, fatigue strength and modulus of elasticity. The conversion factors for structure subject to dynamic loadings (which is subject to fatigue) must also account for differences in material fatigue strengths. Fatigue strengths of both steel (Fs) and aluminum (Fa) will be based on the area under the S-N (stress-number of cycles) fatigue curves between 10^2 and 10^8 cycles. The ratio of these values (Fs/Fa) is 2.2 as given in Reference 4.

Corrosion

A.B.S., in the 1976 steel rules, allows a 10% reduction in steel section moduli and a 10% reduction in plate thicknesses, not to exceed .125", for steel with adequate corrosion resistant coatings. Considering the good corrosion resistance of aluminum, it is considered reasonable to apply this reduction when converting steel scantlings to aluminum scantlings. Therefore, the uncoated steel scantlings will be reduced to the equivalent coated scantlings before applying the conversion factors needed to calculate aluminum scantlings. A.B.S., in the 1975 aluminum rules, also reduces the conversion factors by 10% to account for aluminum's better corrosion resistance.

Abrasion

Abrasion of the tank top and lower wing bulkheads is an important design consideration for bulk ore carriers. It was determined in Reference 3 that aluminum abrades approximately four times faster than mild steel. Therefore, the aluminum abrasion allowance will be four times the steel abrasion allowance. The thickness of an aluminum plate subject to abrasion can then be determined by the following equation:

$$Ta = (Ts - As)\ (Q) + Aa$$

which gives:

$$Ta = (Q)Ts + As(4 - Q)$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Q = the appropriate conversion factor depending on the loading type and orientation

Aa = aluminum abrasion allowance (= 4 As)

As = steel abrasion allowance

MATERIAL CONVERSION FACTORS FOR STATICALLY LOADED STRUCTURE

The basic static material conversion factor is a single number determined by combining the ultimate and yield strengths of the two materials. The relative importance of yield and ultimate is still under widespread debate. Therefore, an equally weighted equation, which is presently used by A.B.S. in converting MS to HTS and MS to Aluminum, will be used for this study:

$$Qs = \frac{(Ys + Us)}{(Ya + Ua)}$$

where;

Ys = yield stress of mild steel

Us = ultimate stress of mild steel

Ya = as welded yield stress of aluminum

Ua = as welded ultimate stress of aluminum

Qs = static material conversion factor

Stiffeners

The minimum section modulus of an aluminum member, not subject to dynamic loads, which is to replace a steel member will be the section modulus of the coated steel member times the static material conversion factor (Qs). It is also necessary to restrict the deflection of aluminum members. This restriction is presently used by A.B.S. because of the lack of data concerning the effect of increased deflections on ship structure. Deflection is restricted by requiring the moment of inertia of the aluminum member to be at least twice that of the coated steel member. For convenience in calculation, both the section modulus and the moment of inertia of a coated steel member are assumed to be equal to 90% of the corresponding values for uncoated steel.

Plating

The conversion factor for changing steel plate thicknesses to aluminum plate thicknesses, where dynamic loads are not a major concern, is dependent on the loading orientation. The effect of in-plane loads can be measured by yield or ultimate tensile and compressive stresses; the effect of normal loads can be measured by bending stresses.

For in-plane tensile or shear loads, the conversion equation is:

$$Ta = (Qs)\ Ts$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Qs = static material conversion factor

For in-plane compressive loads, the conversion equation is:

$$Ta = (Qcs)\ Ts$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Qcs = compressive static conversion factor

To evaluate Qcs, assume that:

$$Qcs = \sigma s / \sigma a$$

where;

σa = in-plane stress of the aluminum plate

σs = in-plane stress of the coated steel plate

In order to maintain equivalent buckling strength the following must be true:

$$\frac{(\sigma cr)a}{(\sigma cr)s} = \frac{\sigma a}{\sigma s}$$

where;

$(\sigma cr)a$ = critical buckling stress of aluminum

$(\sigma cr)s$ = critical buckling stress of steel

The critical buckling stresses of plates having the same dimensions and boundary conditions are directly proportional to ET^2. Therefore,

$$\frac{(\sigma cr)a}{(\sigma cr)s} = \frac{Ea(Ta)^2}{Es(Ts)^2}$$

where;

Ea = the modulus of elasticity of aluminum

Es = the modulus of elasticity of steel

These equations give the formula:

$$Qcs = \sqrt[3]{\frac{Es}{Ea}}$$

This value shall be used in all cases where $\sqrt[3]{\frac{Es}{Ea}}$ is greater than (Qs). If (Qs) is greater, that value shall be used for (Qcs).

For normal loads, the conversion equation is:

$$Ta = (Qns)\ Ts$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Qns = normal static conversion

The conversion factor (Qns) is determined by applying the static material conversion factor (Qs) to the section moduli of the aluminum and steel plates.

$$SMa = (Qs)\ SMs$$

where;

SMa = section modulus of the aluminum plate

SMs = section modulus of the coated steel plate

Since section modulus is based on the thickness squared, the conversion equation becomes:

$$\frac{WTa^2}{6} = (Qs)\ \frac{WTs^2}{6}$$

where;

W = width of plate

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

which reduces to

$$Ta = \sqrt{(Qs)}\ Ts$$

$$\therefore Qns = \sqrt{(Qs)}$$

For combined normal, and tensile or shear loads, the conversion equation is:

$$Ta = (Qnts)\ Ts$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Qnts = combined static conversion factor

The factor (Qnts) will be the average of the normal factor (Qns) and the tensile or shear factor (Qs), so that:

$$Qnts = \frac{(Qns) + (Qs)}{2}$$

For combined normal and compressive loads, the conversion equation is:

$$Ta = (Qncs)\ Ts$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Qncs = combined static conversion factor

The value for the combined static conversion factor (Qncs) shall be taken as the value calculated for (Qs) or (Qcs) or (Qns) whichever is greater.

MATERIAL CONVERSION FACTORS FOR DYNAMICALLY LOADED STRUCTURE

Material fatigue strength is a major concern in dynamically loaded structure. The fatigue strength of aluminum is relatively low and, therefore, must be included in the dynamic material conversion factor. The basic dynamic material conversion factor (Qd) is calculated from the following equation:

$$Qd = 1/2 \left(\frac{Ys}{Ya} + \frac{Fs}{Fa} \right)$$

where;

Ys = yield strength of steel

Ya = as welded yield strength of aluminum

Fs = area under the S-N curve of steel

Fa = area under the S-N curve of aluminum

The equation for (Qd) produces a material factor equally weighted between the yield and fatigue strength ratios. This value shall be used for all cases where it is greater than (Qs). If (Qs) is greater, that value shall be used for (Qd). A.B.S. also uses this equation for structure where dynamic loads are a major concern.

Stiffeners

The minimum section modulus of an aluminum member subject to dynamic loads, which is to replace a steel member, will be the section modulus of the coated steel member times the dynamic material conversion factor (Qd). As in the case of statically loaded structure, the deflection will be restricted by requiring the aluminum moment of inertia to be at least twice that of the coated steel member, and the section modulus and moment of inertia of the coated steel member are assumed to be 90% of the values for uncoated steel.

Plating

Aluminum plate thickness conversion factors will be found for dynamic structure in the same manner as the static plate thickness conversion factors were found. In any case where the dynamic conversion factor is less than the corresponding static conversion factor, the static factor shall be used.

For in-plane tensile or shear loads, the conversion equation is:

$$Ta = (Qd)\ Ts$$

where;

Ta = thickness of the aluminum plate

Ts = thickness of the coated steel plate

Qd = dynamic material conversion factor

For in-plane compressive loads, the conversion equation is:

$$Ta = (Qcd)\ Ts$$

where;

Ta = thickness of aluminum plate

Ts = thickness of coated steel plate

Qcd = compressive dynamic conversion factor = (Qd)

For normal loads, the conversion equation is:

$$Ta = (Qnd)\ Ts$$

where;

Ta = thickness of aluminum plate

Ts = thickness of coated steel plate

Qnd = $\sqrt{(Qnd)}$ = normal dynamic conversion factor

For combined normal, and tensile or shear loads, the conversion equation is:

$$Ta = (Qntd)\ Ts$$

where;

Ta = thickness of aluminum plate

Ts = thickness of coated steel plate

Qntd = $\frac{(Qd) + (Qnd)}{2}$ = combined dynamic conversion factor

For combined normal and compressive loads, the conversion equation is:

$$Ta = (Qncd)\ Ts$$

where;

Ta = thickness of aluminum plate

Ts = thickness of coated steel plate

Qncd = combined dynamic conversion factor

The value for the combined dynamic conversion factor (Qncd) shall be taken as the value calculated for (Qd) or (Qcd) or (Qnd) whichever is greater.

MATERIAL CONVERSION FACTOR FOR STANCHIONS, PILLARS AND STRUTS

The A.B.S. equation governing the design of stanchions, pillars, and struts for steel ships is developed from the critical buckling stress curve using the straight-line method. The A.B.S. equation for steel is:

$$Wa = \left(17.54 - .0644 \frac{l}{r} \right) A$$

where;

Wa = allowable load in (KIPS)

l = column length in (in)

r = radius of gyration (in)

A = area in (in^2)

A similar equation was developed by A.B.S. in the rules for aluminum ships. This equation incorporates a 10% increase to account for corrosion. Using 5456 aluminum properties in the A.B.S. equation gives:

$$Wa = \left(11.51 - .0668 \frac{l}{r} \right) A$$

These two equations do not permit the development of a single formula for direct substitution of aluminum in place of steel. Tables or graphs can be developed to permit such a substitution, but this is a time-consuming effort and is justified only if many such calculations are to be made. When only a few substitutions are needed, as in the case of this sample calculation, a trial-and-error method can be used. The maximum allowable load (Wa) is calculated for the steel member and used as the design load for the aluminum member. Various aluminum sections are tried until one is found which will support that design load. This process is repeated for each stanchion, pillar or strut.

NUMERICAL VALUES

$$Qs = \frac{(Ys + Us)}{(Ya + Ua)} = \frac{(34000 + 58000)}{(19000 + 41000)} = 1.533$$

$$Qcs = \sqrt[3]{\frac{Es}{Ea}} = \sqrt[3]{\frac{29000000}{10300000}} = 1.412$$

$$Qcs < Qs \therefore Qcs = 1.533$$

$$Qns = \sqrt{Qs} = \sqrt{1.533} = 1.238$$

$$Qnts = \frac{Qn + Qs}{2} = \frac{1.238 + 1.533}{2} = 1.386$$

$$Qncs = > (Qs \text{ or } Qcs \text{ or } Qns) = 1.533$$

$$Qd = \frac{1}{2}\left(\frac{Ys}{Ya} + \frac{Fs}{Fa}\right) = \frac{1}{2}\left(\frac{34000}{19000} + 2.2\right) = 1.995$$

$$Qd > Qs \therefore Qd = 1.995$$

$$Qcd = Qd = 1.995$$

$$Qcd > Qcs \therefore Qcd = 1.995$$

$$Qnd = \sqrt{Qd} = \sqrt{1.995} = 1.412$$

$$Qnd > Qns \therefore Qnd = 1.412$$

$$Qntd = \frac{Qd + Qnd}{2} = \frac{1.995 + 1.415}{2} = 1.705$$

$$Qntd > Qnts \therefore Qntd = 1.705$$

$$Qncd = > (Qd \text{ or } Qcd \text{ or } Qnd) = 1.995$$

$$Qncd > Qncs \therefore Qncd = 1.995$$

PART III

SUPPLEMENTARY DATA

WEIGHTS

The midship section and transverse bulkhead designed for the aluminum ship in Appendix E and the corresponding drawings for the steel ship in Appendix D were used to calculate weights of typical weight groups. The ratios of these weights (aluminum/steel) are tabulated below. These values can be used to estimate the weight of any similar aluminum configuration (if the weight of the steel component it replaces is known). The ratio is very accurate for configurations which are closely similar to those used as a base, and are reasonably good for other configurations.

The accuracy of these factors can be improved by calculating weight ratios for additional configurations and developing tables or graphs to cover a wider range of possibilities. This additional work is not justified for a single ship investigation, but would be very helpful if many Material Trade-Off Studies were conducted.

	(1/2 Ship Weights)		
Structural Item	Calculated Aluminum Weight	Calculated Steel Weight	Alum./Steel Weight Ratio
Deck Plating & Longitudinals	777.6 #/Ft	1345.6 #/Ft	.578
Side Shell Plating & Longitudinals	898.6 #/Ft	1426.6 #/Ft	.630
Inner Bottom Plating & Longitudinals	939.6 #/Ft	1205.9 #/Ft	.779 including abrasion allowance
Bottom Shell Plating & Longitudinals	1063.0 #/Ft	1652.8 #/Ft	.643
Lower Tank Side Plating & Longitudinals	494.6 #/Ft	585.6 #/Ft	.845 including abrasion allowance
Upper Tank Side Plating & Longitudinals	370.6 #/Ft	591.8 #/Ft	.626
Bulkhead Plating & Framing	29.28 L. Tons	51.13 L. Tons	.573
Upper Transverse Web Structure	1608.5 #	2929.0 #	.549
Lower Transverse Web Structure	3563.5 #	7380.2 #	.483
Side Shell Stiffeners	309.6 #	659.3 #	.470

FIGURE C-3 - ALUMINUM TO STEEL WEIGHT RATIOS

COSTS

All costs are escalated at 8% from the date of the contract.

1. Installed Cost of Structure

Steel:

Cost of material = 19 ¢/#	=	$426 /l. ton	
Cost of fabrication & erection	=	390	
Total	=	$816 /l. ton	

Aluminum:

Cost of material = 78 ¢/#	=	$1747 /l. ton
Cost of fabrication & erection	=	790
Total		$2537 /l. ton

2. Construction Waste Credit

Steel:

12% of the structural weight is construction waste (cuttings, fit-up allowance, etc.) at 4 ¢/#.

Aluminum:

5% of the structural weight is construction waste at 29 ¢/#.

3. Installed Cost of Machinery

Steel:

Cost of machinery = $383 /SHP

Aluminum:

Cost of machinery (increased 4.1% as recommended in Reference 4. to allow for increased piping cost and for isolation of machinery and equipment) = $399 /SHP

4. Installed Cost of Outfit

Steel:

Cost of Outfit = $5283 /l. ton

Aluminum:

Cost of outfit (increased 5.4% as recommended in Reference 4 to allow for changed fire protection, painting, etc.) = $5568/l. ton

5. Cost of Design

Steel:

Cost of design = $2345000

Aluminum:

Cost of design (increased 30% as recommended in Reference 4 to allow for differences in regulations and design methods, and for increased machinery and outfit complexity) = $3049000

Acquisition Costs Not Affected By Material

6. Overhead = 25% of the sum of categories 1 through 5.

7. Profit = 10% of the sum of categories 1 through 6.

8. Annual Cost of Maintenance and Repair

These costs vary with the size of the ship and power plant, the amount of surface to be painted, etc. For convenience in this sample calculation, this cost is assumed to be proportional to displacement.

Steel:

Cost of maintenance and repair = $878 / l.ton

Aluminum:

Cost of maintenance and repair (increased by 11% to allow for increased machinery and outfit complexity and for higher uninsured repair costs, and decreased by 5.3% to allow for decreased painting costs, for a net increase of 5.7% as recommended in Reference 4) = $928 / l. ton

Operating Costs Not Affected By Material

9. Manning and Subsistence = $1238000/year

10.	Shore Staff	=	$ 80000/year
11.	Hull and Machinery Insurance	=	$ 10000 + (0.007 * construction cost)/year
12.	Protection and Indemnity Insurance	=	$ 70000/year
13.	Fuel	=	$ 75/ton

SPACE

Space requirements do not affect the designs of the ore carrier used for this study, so data were not developed.

VOLUME

The volume of all the structure, or of any structural component, can be found from that structure's weight.

Steel weighs 0.283 pounds per cubic inch and, therefore, occupies 4.58 cubic feet per ton.

Aluminum weighs 0.096 pounds per cubic inch and, therefore, occupies 13.50 cubic feet per ton.

APPENDIX D

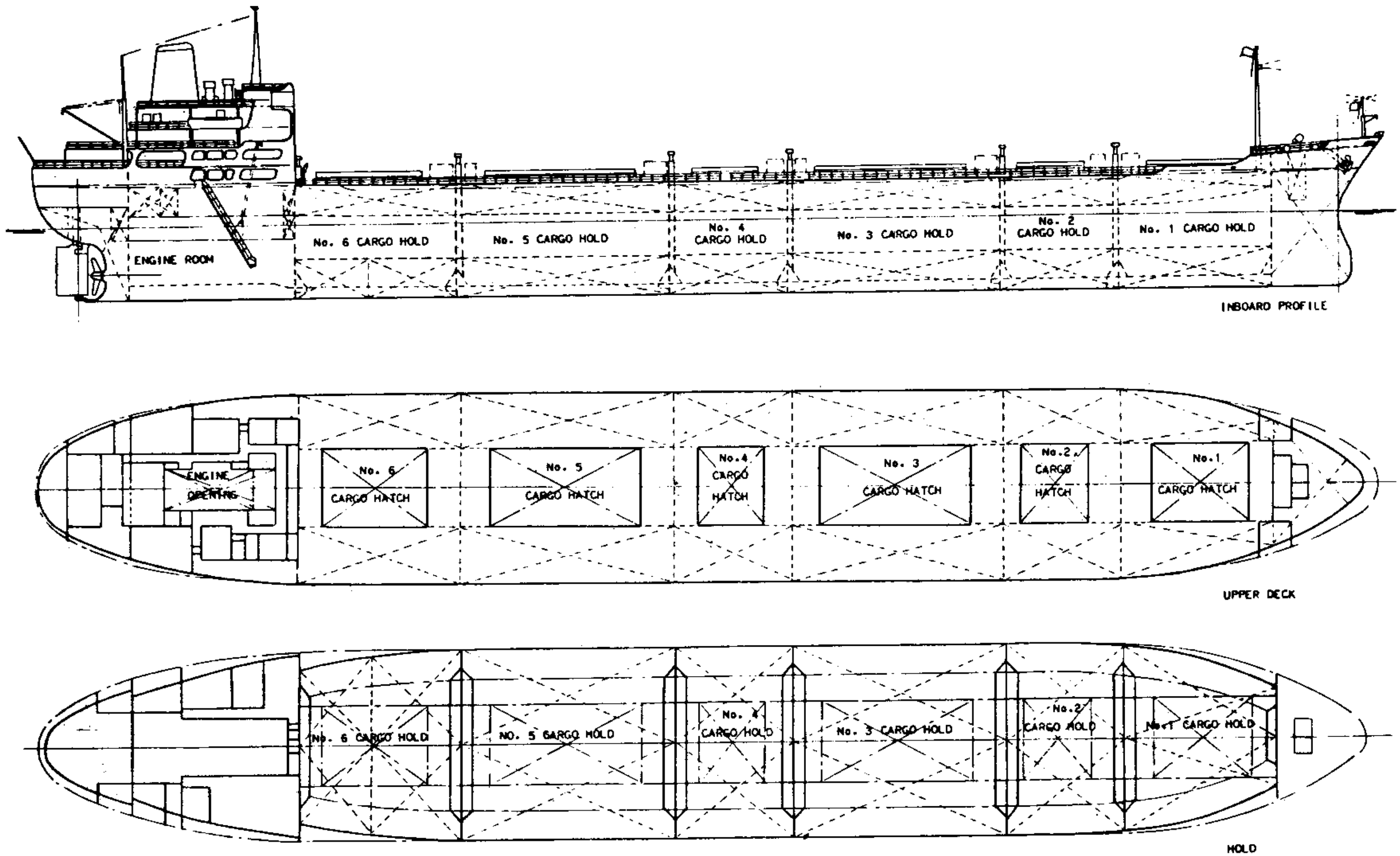
SAMPLE STEEL SHIP DATA BANK

M. V. CHALLENGER

CONTENTS

PRINCIPAL CHARACTERISTICS - M. V. CHALLENGER

LOA	=	632.833 feet
LBP	=	590.542 feet
Beam	=	88.583 feet
Depth	=	52.167 feet
Draft		
Full Load	=	35.75 feet
Light		15.0 feet
Displacement		
Full Load	=	44,750 Long Tons
Light	=	19,571 Long Tons
Light Ship Weight	=	7,892 Long Tons
Total Deadweight	=	36,858 Long Tons
Speed		
Maximum	=	17.4 knots
Full Load	=	14.8 knots
Light	=	16.9 knots
Power		
Maximum	=	9,600 SHP
Full Load	=	8,700 SHP
Ballast	=	7,800 SHP
Built		1965, Mitsubishi Heavy Industries, Ltd.
Classification		ABS A1 E "Bulk Carrier" AMS Strengthened for heavy cargoes
Registration		Monrovia, Liberia, No. 2373
Gross Tonnage		19,633 (Liberian)
Net Tonnage		13,451 (Liberian)
Number of Crew	=	34
Number of Passengers	=	0
Weight		
Structure	=	5920.0 Long Tons
Machinery	=	752.0 Long Tons
Outfit	=	1190.0 Long Tons
Ship Stores	=	100.0 Long Tons
Consumables		90.0 Long Tons
Crew and Effects	=	10.0 Long Tons
Pass. and Effects	=	0.0 Long Tons
Potable Water	=	140.0 Long Tons
Res. Feed Water	=	60.0 Long Tons
Ballast	=	0.0 Long Tons
Fuel	=	1029.0 Long Tons
Cargo	=	35459.0 Long Tons
Range	=	9040 N. Miles
Reserve Fuel	=	2 Days
Fuel Rates	=	.397 #/SHP-HR
Consumables		
Crew	=	10 #/man-day
Pass	=	0
Potable Water		
Crew	=	800 #/man-day
Pass.	=	0



General Arrangement *M.V. Challenger*

FIGURE D-1 - SELECTED MILD STEEL SHIP

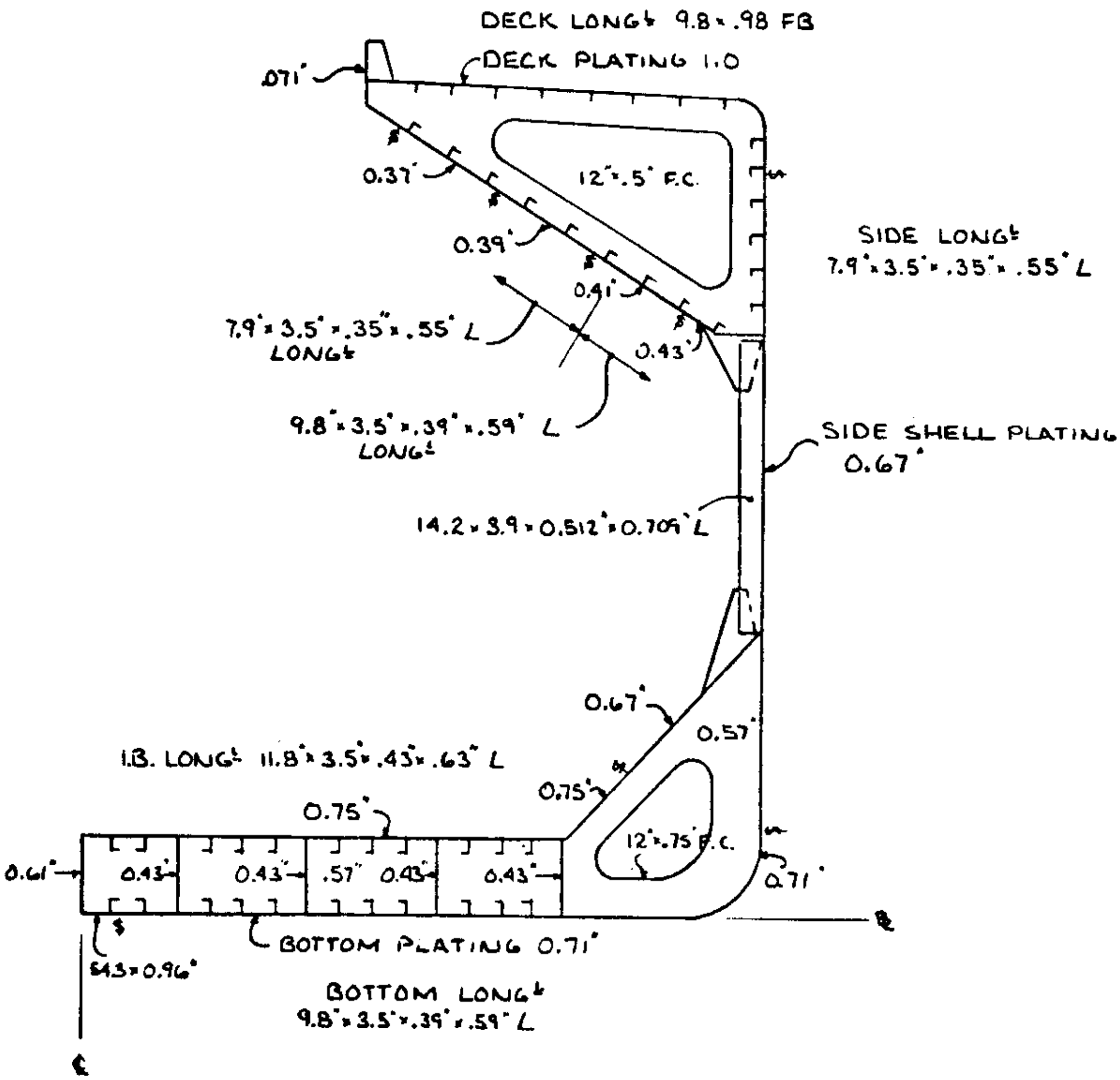
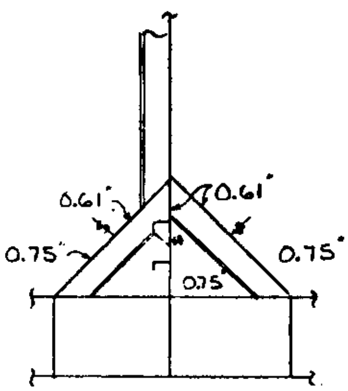
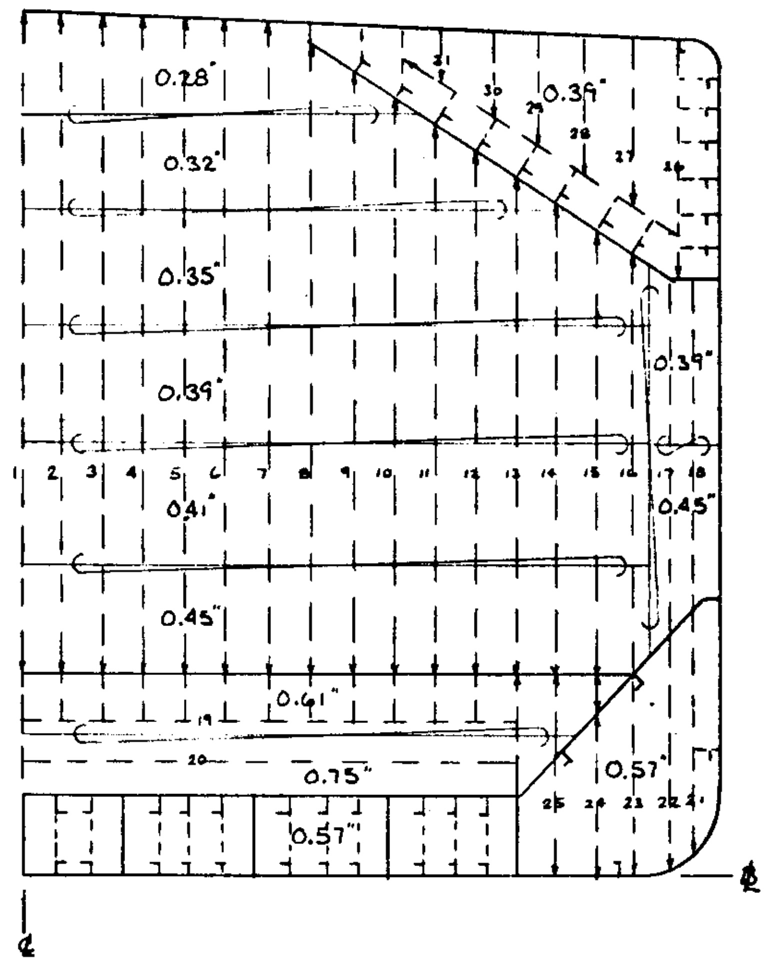


FIGURE D-2 - MILD STEEL MIDSHIP SECTION

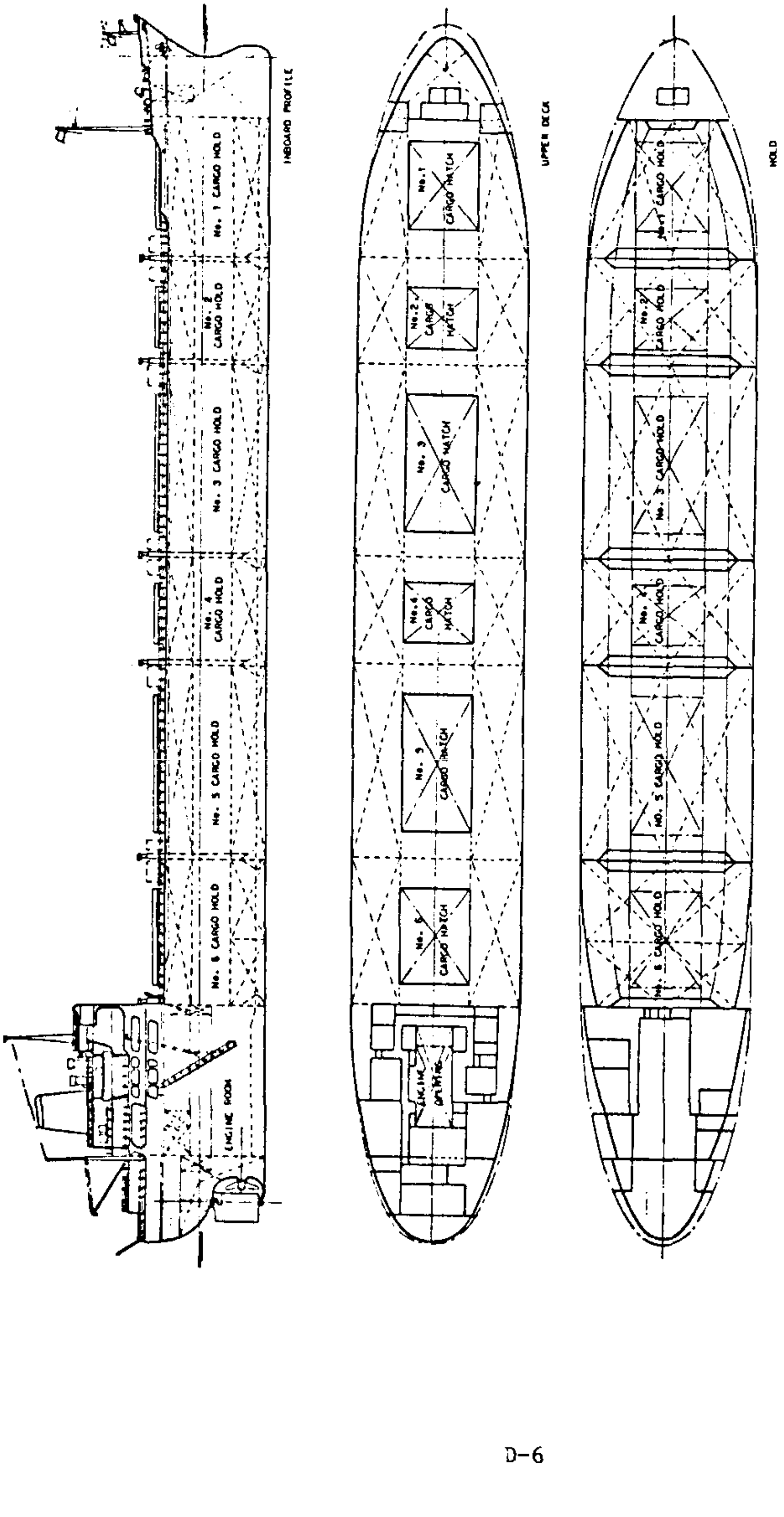




STIFFENERS

1 & 8	27.2 × 9.8 × 0.43 × 0.50 ⊥	19 & 20	7.9 × 3.5 × 0.35 × 0.55 L
2 THRU 7	27.2 × 7.1 × 0.43 × 0.50 ⊥	21 & 22	11.8 × 3.5 × 0.43 × 0.63 L
9 THRU 13	19.7 × 10.6 × 0.39 × 0.50 ⊥	23 THRU 26	9.8 × 3.5 × 0.39 × 0.59 L
14, 15, 16	19.7 × 7.1 × 0.39 × 0.50 ⊥	27 & 32	7.9 × 3.5 × 0.35 × 0.55 L
17, 18	15.8 × 3.9 × 0.51 × 0.71 L	28 THRU 31	5.9 × 3.5 × 0.35 × 0.35 L

FIGURE D-3 - TRANSVERSE WATER TIGHT BULKHEAD MILD STEEL SHIP



TRANSVERSE SPACING

Upper transvers structure = 10.5' = 126"

Lower transverse structure = 7.873' = 94.5"

Side shell stiffening = 31"

Total number of upper transverses = 38

Total number of lower transverses = 53

Total number of shell stiffeners = 172

FIGURE D-4 - TRANSVERSE SPACING

COSTS

ACQUISITION

Structure		$ 4,831,000	
Construction Waste Credit		- 64,000	
Machinery		3,677,000	*
Outfit		6,287,000	*
Design		2,345,000	*
Overhead		4,269,000	*
Profit		2,135,000	*
	Total	$ 23,480,000	

ANNUAL OPERATING

Manning and Subsistence		$ 1,238,000	*
Shore Staff		80,000	*
H & M Insurance		176,000	*
P & I Insurance		70,000	*
Maintenance and Repair		393,000	*
	Total	$ 1,957,000	

* These values are based on Reference 4, escalated at 7% for seven years.

APPENDIX E

SAMPLE STRUCTURAL SYNTHESIS

CONTENTS

STRUCTURAL COMPONENTS AND LOADING

LONGITUDINAL STRUCTURE

STRUCTURE	LOADING TYPE AND ORIENTATION	CONVERSION EQUATION
Side Shell Plating	DYNAMIC - In-Plane (including compressive) and Normal	Ta = Ts (Qncd)
Inner Bottom Plating	DYNAMIC - In-Plane (including compressive) and Normal. High abrasion levels	Ta = Ts (Qncd) + As(4 - Qncd)
Deck Plating Upper Tank Side Plating Bottom and Bilge Turn Plating Longitudinal Framing (in floor) Longitudinal Deck Girder	DYNAMIC - In-Plane (including compressive) and Normal	Ta = Ts (Qncd)
Bottom Longitudinal Inner Bottom Longitudinal Side Longitudinal Deck Longitudinal and Tank Side Longitudinal	DYNAMIC - In-Plane (including compressive) and Normal	SMa = SMs (Qncd) Ia $\geq$ 2Is

STRUCTURAL COMPONENTS AND LOADING

TRANSVERSE STRUCTURE

STRUCTURE	LOADING TYPE AND ORIENTATION	CONVERSION EQUATION
Bulkhead Plating	STATIC - In-Plane (including compressive) and Normal	Ta = Ts (Qncs)
Bulkhead Stiffeners	STATIC - Normal	SMa = SMs (Qns) Ia $\geq$ 2Is
Transverse Floor Plating	STATIC - In-Plane (including compressive) and Normal	Ta = Ts (Qncs)
Transverse Floor Stiffeners Lower Tank Side Girder Bilge Turn Girder Upper Tank Side Girder Transverse Deck Girder and Vertical Side Girder	STATIC - In-Plane (including compressive) and Normal	SMa = SMA (Qncs) Ia $\geq$ 2Is
Side Shell Vertical Stiffeners	DYNAMIC - Normal	SMa = SMs (Qnd) Ia $\geq$ 2Is

LONGITUDINAL STRUCTURE

STRUCTURE	STEEL SCANTLINGS (inches) UNCOATED	STEEL SCANTLINGS (inches) COATED (Ts)	CONVERSION FACTOR (Q)	(Q) * Ts	ABRASION (inches) STEEL (As)	ABRASION (inches) ALUM. As(4-Q)	ALUMINUM SCANTLINGS (inches)
Side Shell Plating	.67	.603	Qncd = 1.995	1.203	-	-	1.203 Use 1.250
Bottom and Bilge Turn Plating	.71	.639	Qncd = 1.995	1.275	-	-	1.275 Use 1.375
Inner Bottom and	.75	.675	Qncd = 1.995	1.347	.2	.401	1.748 Use 1.875
Lower Tank Side Plating	.67	.603	Qncd = 1.995	1.203	.2	.401	1.604 Use 1.75
Deck Plating	1.0	0.90	Qncd = 1.995	1.795	-	-	1.795 Use 1.875
Upper Tank Side	.43	.387	Qncd = 1.995	.772	-	-	.772 Use .8125
	.41	.369	Qncd = 1.995	.736	-	-	.736 Use .75
	.39	.351	Qncd = 1.995	.700	-	-	.700 Use .75
	.37	.333	Qncd = 1.995	.664	-	-	.664 Use .6875
Longitudinal Framing	.61	.549	Qncd = 1.995	1.095	-	-	1.095 Use 1.125
(in floor)	.43	.387	Qncd = 1.995	.772	-	-	.772 Use .8125
Longitudinal Deck Girder	.71	.639	Qncd = 1.995	1.275	-	-	1.275 Use 1.375
Keel Plating	.96	.864	Qncd = 1.995	1.724	-	-	1.724 Use 1.75
Bottom Longitudinal 9.8 x 3.5 x .39 x .59 L On .71" x 24" plt	SM = 29.6 in^3 I = 251.1 in^4	26.64 in^3 225.99 in^4	Qncd = 1.995 I * 2	SM = 53.15 I = 451.9	-	-	Use 10.5 x 5.0 x .625 Flg Plt SM = 53.1 I = 503.7
On .67" x 24" plt	SM = 29.5 in^3 I = 247.0 in^4	26.55 222.3	Qncd = 1.995 I * 2	SM 52.97 I = 444.6	-	-	Use 10.5 x 5.125 x .625 SM = 53.2 I = 498.8

FIGURE E-1 - SCANTLING SUBSTITUTION - LONGITUDINAL STRUCTURE

LONGITUDINAL STRUCTURE

STRUCTURE	STEEL SCANTLINGS (Inches) UNCOATED	COATED (Ts)	CONVERSION FACTOR (Q)	(Q) * Ts	ABRASION (Inches) STEEL (As)	ALUM. As(4-Q)	ALUMINUM SCANTLINGS (Inches)
Inner Bottom Long'l 11.17 x 3.5 x .43 x .63 L On .75 x 24" plt	SM = 41.2 I = 411.6	37.08 370.44	Qncd=1.995 I * 2	SM = 73.97 I = 740.88	-	-	Use 12 x 6 x .625 Flg Plt SM = 74.7 I = 840.0
On .67 x 24" plt	SM = 40.8 I = 398.4	36.72 358.56	Qncd=1.995 I * 2	SM = 73.26 I = 717.1	-	-	Use 12.6 x .625 SM = 73.8 I = 819.2
Side Shell Long'l 7.35 x 3.5 x .35 x .55L on .67 x 24' plt	SM = 20.6 I = 143.6	18.54 129.24	Qncd=1.995 I * 2	SM = 36.99 I = 258.5	-	-	Use 9 x 4 x .625 Flg Plt SM = 37.2 I = 310.4
Deck Longitudinal 9.8 x .98 FB on 1" x 30" plt	SM = 32.4 I = 291.5	29.16 262.35	Qncd=1.995 I * 2	SM = 58.17 I = 524.7	-	-	Use 10.5 x 5.25 x .625 Flg Plt SM = 58.6 I = 605.3
Tank Side Long'l 7.35 x 3.5 x .35 x .55 L On 30" x .37" plt	SM = 19.7 I = 127.6	17.73 114.84	Qncd=1.995 I * 2	SM = 35.37 I = 229.7	-	-	Use 8.75 x 4.5 x .625 Flg Plt SM = 35.8 I = 266.6
Same Angle 7.35 x 3.5 x .35 x .55 L On 30" x .39" plt	SM = 19.8 I = 129.4	17.82 116.46	Qncd=1.995 I * 2	SM = 35.6 I = 232.9	-	-	Use 8.75 x 4.25 x .625 Flg Plt SM = 35.6 I = 269.7
9.21 x 3.5 x .39 x .59 L On 30" x .41" Plt	SM = 29.5 I = 225.8	25.65 203.22	Qncd=1.995 I * 2	SM = 51.17 I = 406.44	-	-	Use 10.75 x 5 x .625 Flg Plt SM = 51.4 I = 462.1
Same Angle 9.21 x 3.5 x .39 x .59 L On .43" x 30" Plt	SM = 28.6 I = 228.9	25.74 206.01	Qncd=1.995 I * 2	SM = 51.35 I = 412.02	-	-	Use 10.75 x 5 x .625 Flg Plt SM = 51.9 I = 473.5

FIGURE E-1 (CONT.) - SCANTLING SUBSTITUTION - LONGITUDINAL STRUCTURE

TRANSVERSE STRUCTURE

STRUCTURE	STEEL SCANTLINGS (Inches)		CONVERSION FACTOR (Q)	(Q) * Ts	ABRASION (Inches)		ALUMINUM SCANTLINGS (Inches)
	UNCOATED	COATED (Ts)			STEEL (As)	ALUM. As(4-Q)	
Bulkhead Plating	.28	.25	Qncs = 1.533	.386	-	-	Use .422
Bulkhead Plating	.32	.288	Qncs = 1.533	.442	-	-	Use .453
Bulkhead Plating	.35	.315	Qncs = 1.533	.483	-	-	Use .500
Bulkhead Plating	.39	.351	Qncs = 1.533	.538	-	-	Use .562
Bulkhead Plating	.41	.369	Qncs = 1.533	.566	-	-	Use .594
Bulkhead Plating	.45	.405	Qncs = 1.533	.621	-	-	Use .625
Bulkhead Plating	.61	.549	Qncs = 1.533	.842	.2	.49	1.33 Use 1.375
Bulkhead Plating	.75	.675	Qncs = 1.533	1.035	.2	.49	1.52 Use 1.50
Bulkhead Plating	.57	.513	Qncs = 1.533	.786	-	-	Use .812
Bulkhead Plating	.61	.549	Qncs = 1.533	.842	-	-	Use .875
Bulkhead Plating	.75	.675	Qncs = 1.533	1.035	-	-	Use 1.125
Bulkhead Stiff. 27.2 x 9.8 x .43 x .5 T On .45" x 27" Plt	SM = 201.7 I = 3489.0	181.5 3140.1	Qns = 1.238 I * 2	SM = 224.73 I = 6280.2	-	-	Use 32 x 10 x .688 Flg Plt SM = 360.5 I = 7088
27.2 x 7.1 x .43 x .5 T On .45" x 27" Plt	SM = 169.6 I = 3077.3	152.64 2769.6	Qns = 1.238 I * 2	SM = 188.97 I = 5539.2	-	-	32 x 10 x .688 Flg Plt SM = 324.5 I = 6113
19.7 x 10.6 x .39 x .5 T On .45" x 27" Plt	SM = 135.7 I = 1736.5	122.13 1562.85	Qns = 1.238 I * 2	SM = 151.2 I = 3125.7	-	-	24 x 10 x .625 Flg Plt SM = 225.8 I = 3497.0

FIGURE E-2 - SCANTLING SUBSTITUTIONS - TRANSVERSE STRUCTURE

TRANSVERSE STRUCTURE (Cont'd)

STRUCTURE	STEEL SCANTLINGS (Inches) UNCOATED	STEEL SCANTLINGS (Inches) COATED (Ts)	CONVERSION FACTOR (Q)	(Q) * Ts	ABRASION (Inches) STEEL (As)	ABRASION (Inches) ALUM. As(4-Q)	ALUMINUM SCANTLINGS (Inches)
Bulkhead Stiff.(Cont'd) 15.8 x 3.9 x .51 x .71 L On .45" x 27" Plt	SM = 71.6 I = 820.1	64.44 738.1	Qns = 1.238 I * 2	SM = 79.8 I = 1476	-	-	19 x 9 x .5 Flg Plt SM = 126.8 I = 1659.7
7.9 x 3.5 x .35 x .55 L On .75" x 33" Plt	SM = 21 I = 155.4	18.9 135.86	Qns = 1.238 I * 2	23.40 271.72	-	-	9 x 6 x .51 Flg Plt SM = 38.8 I = 319.0
11.8 x 3.5 x .43 x .63 L On .57" x 33 Plt	SM = 40.8 I = 407.9	36.72 367.11	Qns = 1.238 I * 2	45.46 734.22	-	-	13 x 9 x .5 Flg Plt SM = 80.0 I = 828.5
9.8 x 3.5 x .39 x .59 L On .57" x 33" Plt	SM = 29.4 I = 251.4	26.46 226.3	Qns = 1.238 I * 2	32.76 452.52	-	-	11.5 x 6 x .5 Flg Plt SM = 52.1 I = 506.2
7.9 x 3.5 x .35 x .55 L On .39" x 23" Plt	SM = 19.5 I = 121.6	17.55 109.4	Qns = 1.238 I * 2	21.73 218.9	-	-	9 x 6 x .5 Flg Plt SM = 34.6 I = 220.9
5.9 x 3.5 x .35 x .55 L On 39" x 23" Plt	SM = 10.2 I = 51.2	9.18 46.08	Qns = 1.238 I * 2	11.37 92.16	-	-	7 x 4 x .5 Flg Plt SM = 19.4 I = 111.1
Transverse Floor Plating	.57	.513	Qncs=1.533	.786	-	-	.812
Trans. Floor Stiffeners	SM = 29.4 I = 251.4	26.5 226.3	Qncs=1.533 I * 2	40.56 452.5	-	-	SM = 46.88 I = 512.7

FIGURE E-2 (CONT.) - SCANTLING SUBSTITUTIONS - TRANSVERSE STRUCTURE

TRANSVERSE STRUCTURE

STRUCTURE	STEEL SCANTLINGS (Inches)		CONVERSION FACTOR (Q)	(Q) * Ts	ABRASION (Inches)		ALUMINUM SCANTLINGS (Inches)
	UNCOATED	COATED (Ts)			STEEL (As)	ALUM. As(4-Q)	
Lower Tankside Girder 24 x 12 x .57 x .75 T	SM = 289.8 I = 4487.8	260.8 4039.02	Qncs=1.533 I * 2	399.8 8078.04	-	-	26 x 12 x .812 x 1.0 T SM = 469.1 I = 9361.5
Bilge Turn Girder 36 x 12 x .57 x .75 T	SM = 480.5 I = 105.30	432.45 9477	Qncs=1.533 I * 2	662.9 1895.4	-	-	40 x 12 x .812 x 1.0 T SM = 790.0 I = 2104.2
Upper Tankside Girder 24 x 12 x .39 x .5 T	SM = 189.1 I = 2675.0	170.2 2407.5	Qncs=1.533 I * 2	260.9 4815	-	-	26 x 12 x .625 x .75 T SM = 327.3 I = 5411.7
Transv. Deck Girder 24 x 12 x .39 x .5	SM = 208.1 I = 3798.4	187.3 3418.6	Qncs = 1.533 I * 2	287.11 6837.1	-	-	26 x 12 x .625 x .75 T SM = 363.7 I = 7624.1
Vert. Side Girder 24 x 12 x .39 x .5	SM = 200.4 * = 3301.2	180.4 2971.08	Qncs=1.533 I * 2	276.5 5942.16	-	-	26 x 12 x .625 x .75 T SM = 347.6 I = 6593.8
Vert. Side Shell Stiffeners 14 x 2 x 3.9 x .512 x .709	SM = 63.6 I = 706.3	57.24 635.7	Qnd = 1.412 I * 2	80.8 1271.3	-	-	17.5 x 4 x .625 SM = 98.0 I = 1457.6

FIGURE E-2 (CONT.) - SCANTLING SUBSTITUTIONS - TRANSVERSE STRUCTURE

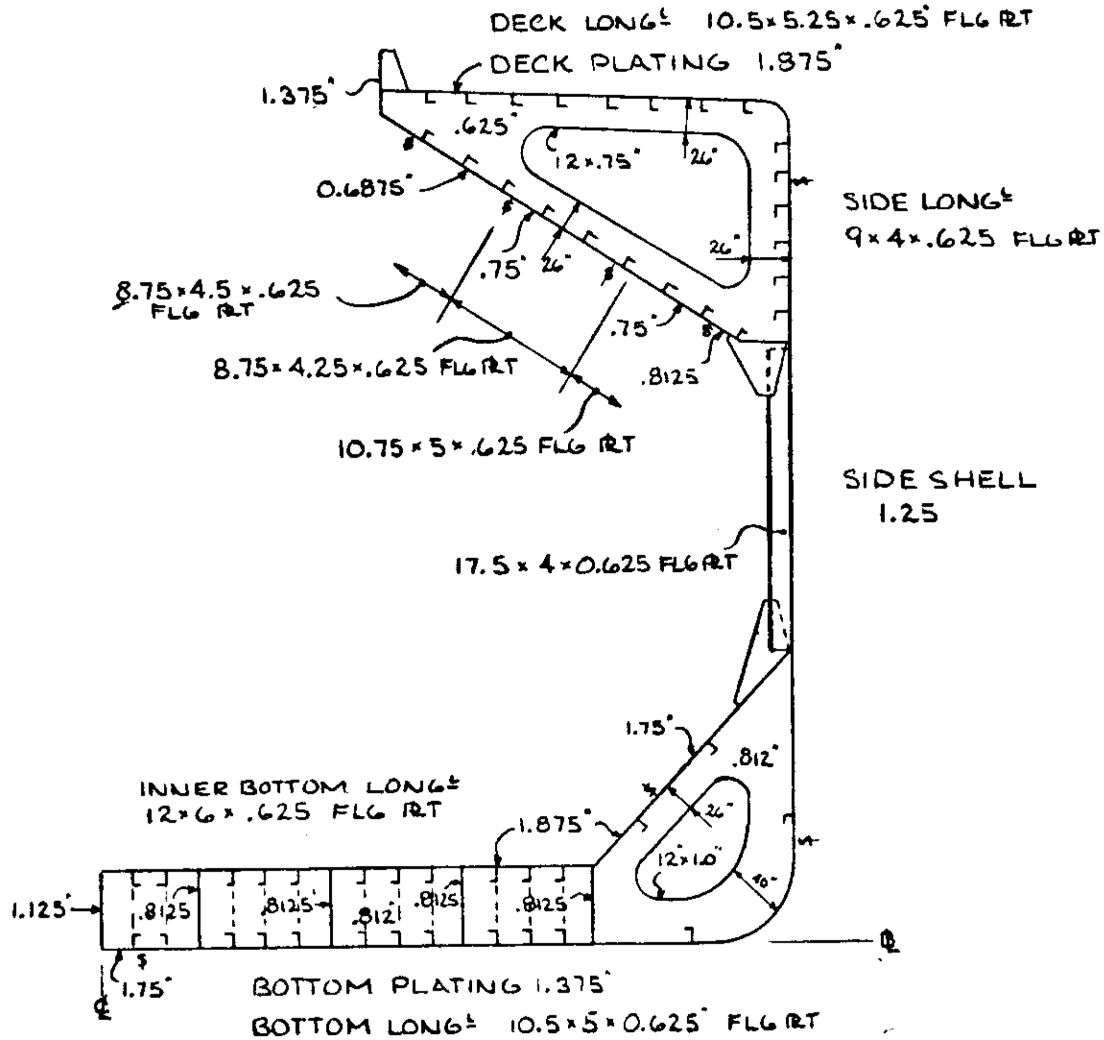
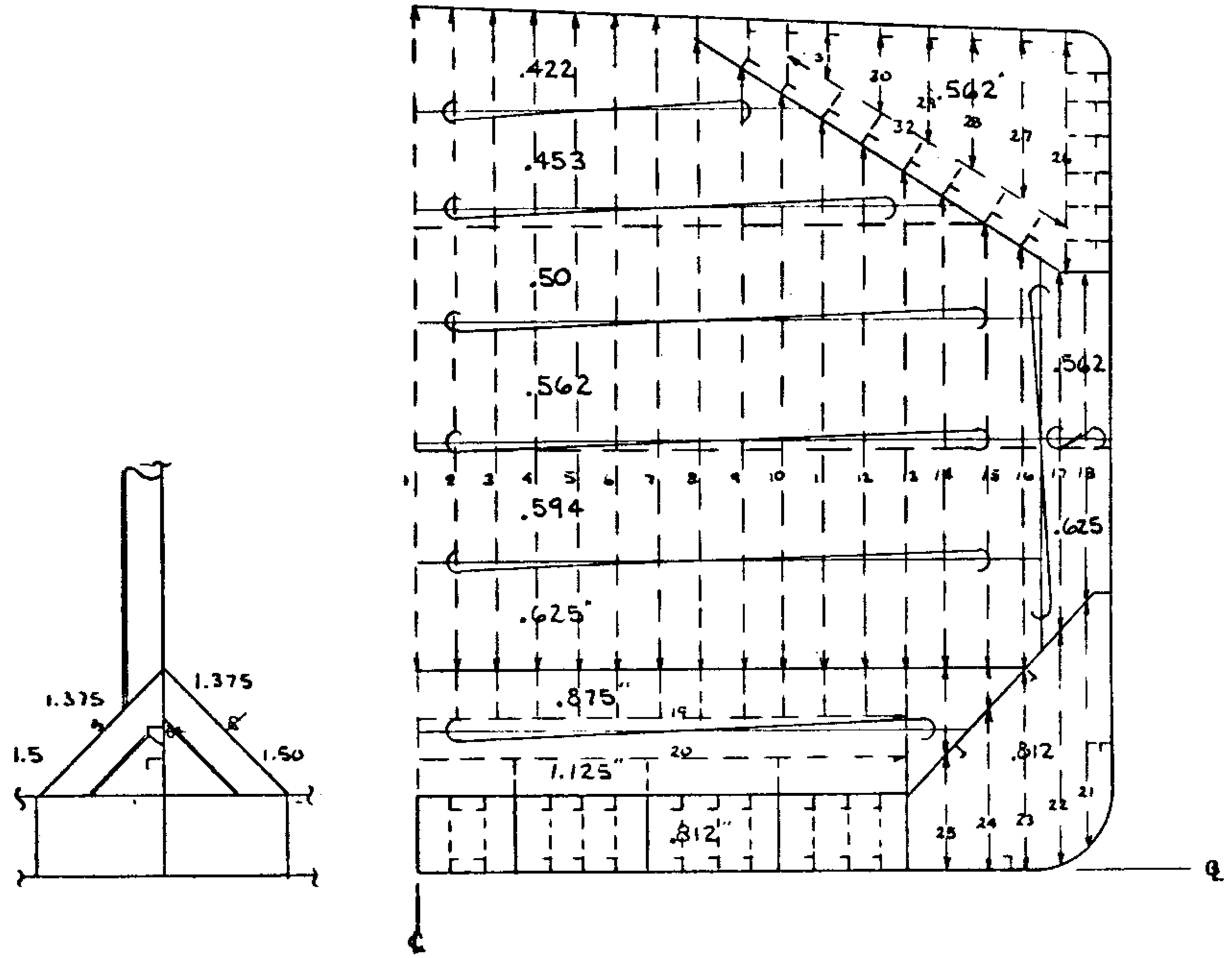


FIGURE E-3 - ALUMINUM MIDSHIP SECTION



STIFFENERS	
1 & 8	32 × 10 × .688 FLG PLT
2 THRU 7	30 × 10 × .688 FLG PLT
9 THRU 13	24 × 10 × .625 FLG PLT
14 15 16	22 × 10 × .625 FLG PLT
17 & 18	19 × 9 × .5 FLG PLT

STIFFENERS	
19 & 20	9 × 6 × .5 FLG PLT
21 & 22	13 × 9 × .5 FLG PLT
23 THRU 26	11.5 × 6 × .5 FLG PLT
27 & 32	9 × 6 × .5 FLG PLT
28 THRU 31	7 × 4 × .5 FLG PLT

FIGURE E-4 - TRANSVERSE WATERTIGHT BULKHEAD ALUMINUM SHIP

VERIFICATION OF ALUMINUM DESIGN SUITABILITY

COMPATIBILITY AT STRUCTURAL COMPONENT INTERFACES

The aluminum components have the same configurations and stiffener spacings as the steel components, so there is no problem with misalignment of stiffeners. Some of the aluminum stiffeners are deeper than the steel stiffeners and have wider flanges. These stiffeners were reviewed to be sure that the added depth and width did not create physical interferences or close off needed access. No such problems were found.

LONGITUDINAL STRENGTH AND STIFFNESS

The longitudinal hull girder must meet the same criteria as other ship stiffeners under dynamic loading. These criteria are:

$$SM_A = 0.9\ (Q_d)\ SM_{us}$$

$$I_A = 0.9\ (2)\ I_{us}$$

where;

SM_A = Section modulus - aluminum

SM_{us} = Section modulus - uncoated steel

I_A = Moment of inertia - aluminum

I_{us} = Moment of inertia - uncoated steel

Q_d = Dynamic conversion factor (= 1.995)

I/y at Deck

steel ship		67090 in^2-ft
minimum for alum. ship	=	120500 in^2-ft
actual for alum. ship	=	124700 in^2-ft

I/y at Bottom

steel ship	=	89400 in^2-ft
minimum for alum. ship	=	160500 in^2-ft
actual for alum. ship	=	185700 in^2-ft

Moment of Inertia

steel ship	=	$2.113 * 10^6$ in^2-ft^2
minimum for alum. ship	=	$3.803 * 10^6$ in^2-ft^2
actual for alum. ship	=	$3.954 * 10^6$ in^2-ft^2

ALUMINUM SHIP STRUCTURAL WEIGHTS

The steel ship structure was divided into major weight groups. The weight of each group was multiplied by the appropriate (aluminum/steel) weight ratio from Part III of the Data Bank, and the products summed to obtain the aluminum ship structural weight.

Weight Group	Steel Ship Weight (Long Tons)	Alum/Steel Ratio (from Part III of Data Bank)	Aluminum Ship Weight (Long Tons)
Deck Plating & Longitudinals	750	.578	434
Side Shell Plating and Longitudinals	850	.630	535
Inner Bottom Plating and Longitudinals	800	.779	623
Bottom Shell Plating and Longitudinals	1050	.643	675
Tank Side Plating and Longitudinals	560	.735	412
Bulkhead Plating and Framing	920	.573	527
Upper Transverse Web	120	.549	66
Lower Transverse Web	300	.483	145
Side Shell Stiffener	140	.470	66
Deckhouse	130	.567*	74
Superstructure	120	.567*	68
Foundations	110	.567*	62
Welding and Riveting	70	.567*	40
Total	5920	.630	3727

* The average of the other ratios (neglecting those ratios that include abrastion).

ALUMINUM SHIP CHARACTERISTICS

Aluminum Ship	
LOA (ft)	= 632.833 feet
LBP (ft)	= 590.542 feet
Beam (ft)	= 88.583 feet
Depth (ft)	= 52.167 feet
Draft - Full Load	= 35.75 feet
Light	= 15.0 feet
Displacement	
Full Load	= 44,750 long tons
Ballast	= 19,571 long tons
Light Ship Weight	= 5,474 long tons
Total Deadweight	= 39,276 long tons
Speed	
Maximum	= 17.4 knots
Full Load	= 14.8 knots
Ballast	= 16.9 knots
Power	
Maximum	= 9,600 SHP
Full Load	= 8,700 SHP
Ballast	= 7,800 SHP
Number of Crew	= 34
Number of Passengers	= 0
Weight	
Structure	= 3,727 long tons
Machinery	= 720 long tons
Outfit	= 1,027 long tons
Ship Stores	= 100 long tons
Consumables	= 90 long tons
Crew and Effects	= 10 long tons
Pass. and Effects	= 0 long tons
Potable Water	= 140 long tons
Res. Feedwater	= 60 long tons
Ballast	= 0 long tons
Fuel	= 1,029 long tons
Cargo	= 37,847 long tons
Range	= 9,099 nautical miles

ALUMINUM SHIP CHARACTERISTICS (Cont'd)

Reserve Fuel Days	= 2
Ruel Rate (#/SHP-Hr)	= .397 #/SHP-hr
Consumables	
Crew	= 10 #/man-day
Passenger	= 0
Potable Water	
Crew	= 800 #/man-day
Passengers	= 0
Cargo Capacity of Steel Ship	= 35,459 long tons

APPENDIX F

SAMPLE DESIGN OPTIMIZATION

CONTENTS

Page No.

SAMPLE DESIGN OPTIMIZATION

A simple computer program was written to validate the formulas and flow chart described in the section "DESIGN OPTIMIZATION." This program was used to develop two alternate modifications to the aluminum ship design developed in Appendix E.

Ship characteristics for the aluminum vessel of Appendix E (same geometry as steel ship) were input. Figure F1 tabulates those data. For each of the alternate designs, the desired modified cargo capacity was input. The computer calculated a new ship displacement and horsepower, and modified the ship characteristics accordingly. Figures F2 and F3 tabulate these modified data for a ship with the same cargo capacity as the steel ship, and a ship with the cargo capacity increased 5% above that of the aluminum ship of Figure F1.

```
ALUMINUM SHIP OPTIMIZATION
DESIGN NUMBER    0       AT  3.114 ON 11/16/78
(1) LENGTH OVERALL          = 632.83 FEET
(2) LENGTH BETWEEN PERPS.   = 590.54 FEET
(3) BEAM                    =  88.53 FEET
(4) DEPTH                   =  52.17 FEET
(5/6) DRAFT                 =  35.15 FEET (LOADED)        =  15.00 (LIGHT)
(7/8) DISPLACEMENT          =  44750 LONG TONS (LOADED) =  19571 (LIGHT)
(9) MAXIMUM SPEED           =   17.4 KNOTS
(10/11) SERVICE SPEED       =   14.8 KNOTS (LOADED)       =   16.9 (LIGHT)
(12) MAXIMUM POWER          =   9500 SHP
(13/14) SERVICE POWER       =   8700 SHP (LOADED)         =   7300 (LIGHT)
(15/16) NUMBER OF PEOPLE    =     34 (CREW)               =      0 (PASS.)
(17) WEIGHT-STRUCTURE       =   3727 LONG TONS
(18)       -MACHINERY       =    720 LONG TONS
(19)       -OUTFIT          =   1027 LONG TONS
(20)       -SHIP STORES     =    100 LONG TONS
(21)       -CONSUMABLES     =     90 LONG TONS
(22)       -CREW & EFFECTS  =     10 LONG TONS
(23)       -PASS.& EFFECTS  =      0 LONG TONS
(24)       -POTABLE WATER   =    140 LONG TONS
(25)       -RES.FEED WATER  =     60 LONG TONS
(26)       -BALLAST         =      0 LONG TONS
(27)       -FUEL            =   1029 LONG TONS
(28)       -CARGO           =  37347 LONG TONS
(29) RESERVE FUEL           =      2 DAYS
(30)                        =     81 TONS
(31)                        =    825 NAUTICAL MILES
(32/33) MAX.VOYAGE LENGTH   =   25.6 DAYS (LOADED)        =   28.6 (LIGHT)
(34/35)                     =   9099 MILES (LOADED)       =  11529 (LIGHT)
(36/37) BLOCK COEF.         =  .8518 (LOADED)             =  .8729 (LIGHT)
(38) LENGTH-BEAM RATIO      =   6.67
(39) LENGTH-DEPTH RATIO     =  11.32
(40/41) BEAM-DRAFT RATIO    =   2.52 (LOADED)             =   5.91 (LIGHT)
(42/43) DISPL-LENGTH RATIO= 217.29 (LOADED)             =  95.03 (LIGHT)
(44) SPEED-LENGTH RATIO     =    .72
(45) ADMIRALTY COEF.        = 691.63 (MAX. SPEED)
(46/47) ADMIRALTY COEF.     = 469.67 (LOADED)             = 449.41 (LIGHT)
(48) FUEL RATE              =   .397 POUNDS/SHP/HOUR
(49) MACHINERY WEIGHT       =168.000 POUNDS/SHP
(50) RES.FEED WATER         = 14.000 POUNDS/SHP
(51/52) CONSUMABLES         =   10.0 LB/MAN/DAY (CREW)    =     .0 (PASS.)
(53/54) CONSUM.DAYS         =    593 DAYS (CREW)          =      0 (PASS.)
(55/56) POTABLE WATER       =  800.0 LB/MAN/DAY (CREW)    =     .0 (PASS.)
(57/58) POT.WATER DAYS      =     12 DAYS (CREW)          =      0 (PASS.)
(59) STRUCT/DISPL RATIO     =  .0833
(60) OUTFIT/DISPL RATIO     =  .0229
(61) STORES/DISPL RATIO     =  .0022
(62/63) WEIGHT/MAN          =    659 LB/MAN (CREW)        =      0 (PASS.)
(64) BALLAST/DISPL RATIO    =  .0000
```

FIGURE F-1 - SAME GEOMETRY SHIP

```
ALUMINUM SHIP OPTIMIZATION
DESIGN NUMBER    1        AT  8.114 ON 11/16/78
(1) LENGTH OVERALL          = 613.54 FEET
(2) LENGTH BETWEEN PERPS.   = 578.13 FEET
(3) BEAM                    =  86.72 FEET
(4) DEPTH                   =  51.07 FEET
(5/6) DRAFT                 =  34.41 FEET (LOADED)        =  14.68 (LIGHT)
(7/8) DISPLACEMENT          =  41990 LONG TONS (LOADED)   =  18363 (LIGHT)
(9) MAXIMUM SPEED           =   17.4 KNOTS
(10/11) SERVICE SPEED       =   14.9 KNOTS (LOADED)       =   16.9 (LIGHT)
(12) MAXIMUM POWER          =   9201 SHP
(13/14) SERVICE POWER       =   8338 SHP (LOADED)         =   7476 (LIGHT)
(15/16) NUMBER OF PEOPLE    =     34 (CREW)               =      0 (PASS.)
(17) WEIGHT-STRUCTURE       =   3497 LONG TONS
(18)       -MACHINERY       =    690 LONG TONS
(19)       -OUTFIT          =    964 LONG TONS
(20)       -SHIP STORES     =     94 LONG TONS
(21)       -CONSUMABLES     =     90 LONG TONS
(22)       -CREW & EFFECTS  =     10 LONG TONS
(23)       -PASS.& EFFECTS  =      0 LONG TONS
(24)       -POTABLE WATER   =    140 LONG TONS
(25)       -RES.FEED WATER  =     59 LONG TONS
(26)       -BALLAST         =      0 LONG TONS
(27)       -FUEL            =    937 LONG TONS
(28)       -CARGO           =  35459 LONG TONS
(29) RESERVE FUEL           =      2 DAYS
(30)                        =     79 TONS
(31)                        =    835 NAUTICAL MILES
(32/33) MAX.VOYAGE LENGTH   =   25.6 DAYS (LOADED)        =   28.6 (LIGHT)
(34/35)                     =   9102 MILES (LOADED)       =  11593 (LIGHT)
(36/37) BLOCK COEF.         =  .5513 (LOADED)             =  .3729 (LIGHT)
(38) LENGTH-BEAM RATIO      =   6.67
(39) LENGTH-DEPTH RATIO     =  11.32
(40/41) BEAM-DRAFT RATIO    =   2.52 (LOADED)             =   5.91 (LIGHT)
(42/43) DISPL-LENGTH RATIO  = 217.30 (LOADED)             =  95.03 (LIGHT)
(44) SPEED-LENGTH RATIO     =    .72
(45) ADMIRALTY COEF.        = 591.69 (MAX. SPEED)
(46/47) ADMIRALTY COEF.     = 469.69 (LOADED)             = 449.41 (LIGHT)
(48) FUEL RATE              =   .397 POUNDS/SHP/HOUR
(49) MACHINERY WEIGHT       =168.000 POUNDS/SHP
(50) RES.FEED WATER         = 14.000 POUNDS/SHP
(51/52) CONSUMABLES         =   10.0 LB/MAN/DAY (CREW)    =     .0 (PASS.)
(53/54) CONSUM.DAYS         =    593 DAYS (CREW)          =      0 (PASS.)
(55/56) POTABLE WATER       =  300.0 LB/MAN/DAY (CREW)    =     .0 (PASS.)
(57/58) POT.WATER DAYS      =     12 DAYS (CREW)          =      0 (PASS.)
(59) STRUCT/DISPL RATIO     =  .0833
(60) OUTFIT/DISPL RATIO     =  .0229
(61) STORES/DISPL RATIO     =  .0022
(62/63) WEIGHT/MAN          =    659 LB/MAN (CREW)        =      0 (PASS.)
(64) BALLAST/DISPL RATIO    =  .0000
```

FIGURE F-2 - SAME CAPACITY SHIP

```
ALUMINUM SHIP OPTIMIZATION
DESIGN NUMBER    2        AT  8.114 ON 11/16/73
(1) LENGTH OVERALL          = 642.99 FEET
(2) LENGTH BETWEEN PERPS.   = 600.01 FEET
(3) BEAM                    =  90.00 FEET
(4) DEPTH                   =  53.00 FEET
(5/6) DRAFT                 =  35.71 FEET (LOADED)        =  15.24 (LIGHT)
(7/8) DISPLACEMENT          =  46933 LONG TONS (LOADED)   =  20527 (LIGHT)
(9) MAXIMUM SPEED           =   17.4 KNOTS
(10/11) SERVICE SPEED       =   14.9 KNOTS (LOADED)       =   16.9 (LIGHT)
(12) MAXIMUM POWER          =   9910 SHP
(13/14) SERVICE POWER       =   8931 SHP (LOADED)         =   8052 (LIGHT)
(15/16) NUMBER OF PEOPLE    =     34 (CREW)               =      0 (PASS.)
(17) WEIGHT-STRUCTURE       =   3909 LONG TONS
(18)       -MACHINERY       =    743 LONG TONS
(19)       -OUTFIT          =   1077 LONG TONS
(20)       -SHIP STORES     =    105 LONG TONS
(21)       -CONSUMABLES     =     90 LONG TONS
(22)       -CREW & EFFECTS  =     10 LONG TONS
(23)       -PASS.& EFFECTS  =      0 LONG TONS
(24)       -POTABLE WATER   =    140 LONG TONS
(25)       -RES.FEED WATER  =     62 LONG TONS
(26)       -BALLAST         =      0 LONG TONS
(27)       -FUEL            =   1063 LONG TONS
(28)       -CARGO           =  39739 LONG TONS
(29) RESERVE FUEL           =      2 DAYS
(30)                        =     84 TONS
(31)                        =    835 NAUTICAL MILES
(32/33) MAX.VOYAGE LENGTH   =   25.6 DAYS (LOADED)        =   28.6 (LIGHT)
(34/35)                     =   9105 MILES (LOADED)       =  11595 (LIGHT)
(36/37) BLOCK COEF.         =  .5518 (LOADED)             =  .3729 (LIGHT)
(38) LENGTH-BEAM RATIO      =   6.67
(39) LENGTH-DEPTH RATIO     =  11.32
(40/41) BEAM-DRAFT RATIO    =   2.52 (LOADED)             =   5.91 (LIGHT)
(42/43) DISPL-LENGTH RATIO  = 217.29 (LOADED)             =  95.03 (LIGHT)
(44) SPEED-LENGTH RATIO     =    .71
(45) ADMIRALTY COEF.        = 591.59 (MAX. SPEED)
(46/47) ADMIRALTY COEF.     = 469.63 (LOADED)             = 449.41 (LIGHT)
(48) FUEL RATE              =   .397 POUNDS/SHP/HOUR
(49) MACHINERY WEIGHT       =168.000 POUNDS/SHP
(50) RES.FEED WATER         = 14.000 POUNDS/SHP
(51/52) CONSUMABLES         =   10.0 LB/MAN/DAY (CREW)    =     .0 (PASS.)
(53/54) CONSUM.DAYS         =    593 DAYS (CREW)          =      0 (PASS.)
(55/56) POTABLE WATER       =  300.0 LB/MAN/DAY (CREW)    =     .0 (PASS.)
(57/58) POT.WATER DAYS      =     12 DAYS (CREW)          =      0 (PASS.)
(59) STRUCT/DISPL RATIO     =  .0833
(60) OUTFIT/DISPL RATIO     =  .0229
(61) STORES/DISPL RATIO     =  .0022
(62/63) WEIGHT/MAN          =    659 LB/MAN (CREW)        =      0 (PASS.)
(64) BALLAST/DISPL RATIO    =  .0000
```

FIGURE F-3 - INCREASED CAPACITY SHIP

APPENDIX G

SAMPLE ECONOMIC EVALUATION

CONTENTS

Page No.

SAMPLE ECONOMIC EVALUATION

This economic evaluation used the computer program GENEC, described in Appendix A, to calculate RFR's for the steel ship and for the three aluminum ships developed in Appendix F. Simplified numerical data were used for this calculation, based primarily on Reference 4. More detailed data should be used for a specific Material Trade-Off Study. The program has the capability of accepting any additional data needed to suit conditions which occur in practice.

ECONOMIC ASSUMPTIONS

The discount rate is 9%.

Material scrap value escalates at 5%, and all costs escalate at 8% from the date of the contract.

The construction time for all ships is 30 months.

The ship life is 25 years for the steel vessel and 30 years for aluminum vessels.

All ships will operate 360 days per year.

All ships will have 34-man crews.

Adequate cargo will be available when needed.

RFR is calculated before taxes.

RFR is based on operating costs for the first five years of ship life.

VOYAGE INFORMATION

The voyage is from Seattle to Yokohama (4,280 nautical miles) loaded, with return in ballast.

Ship will spend 1.5 days in each port and will consume 6 tons of fuel per day in port.

SHIP INFORMATION

Steel ship information is tabulated in Appendix D.

Aluminum ship information (three designs) is tabulated in Appendix F.

COST INFORMATION

Fuel Costs

Fuel cost is $75 per long ton, escalated at 8% from the date of contract.

Acquisition Costs

Cost formulas are given in Part III of the Data Bank.

		Steel Ship (Append.D)	Same Geometry Alum. Ship	Same Capacity Alum. Ship	Increased Capacity Alum. Ship
1.	Structure	4,831,000	9,455,000	8,872,000	9,917,000
2.	Construction Waste Credit	- 64,000	- 121,000	- 114,000	- 123,000
3.	Machinery	3,677,000	3,830,000	3,671,000	3,954,000
4.	Outfit	6,287,000	5,718,000	5,368,000	5,997,000
5.	Design	2,345,000	2,814,000	2,814,000	2,814,000
	Subtotal	17,076,000	21,696,000	20,611,000	22,559,000
6.	Overhead (25%)	4,269,000	5,424,000	5,153,000	5,640,000
	Subtotal	21,345,000	27,120,000	25,764,000	28,199,000
7.	Profit (10%)	2,135,000	2,712,000	2,576,000	2,820,000
	Total	23,480,000	29,832,000	28,340,000	31,019,000

Operating Costs

Cost formulas are given in Part III of the Data Bank.

		Steel Ship (Append.D)	Same Geometry Alum. Ship	Same Capacity Alum. Ship	Increased Capacity Alum. Ship
1.	Manning and Subsistence	1,238,000	1,238,000	1,238,000	1,238,000
2.	Shore Staff	80,000	80,000	80,000	80,000
3.	H&M Insurance	176,000	219,000	208,000	227,000
4.	P&I Insurance	70,000	70,000	70,000	70,000
5.	Maintenance & Repair	393,000	415,000	390,000	436,000
	Total	1,957,000	2,022,000	1,986,000	2,051,000

Scrap Value

	Steel Ship (Append.D)	Same Geometry Alum. Ship	Same Capacity Alum. Ship	Increased Capacity Alum. Ship
Scrap Value	530,000	2,421,000	2,272,000	2,539,000

COMPUTER RESULTS

Input and output for the four computer runs is shown in Figures G1 through G4. The resulting RFR's are plotted against cargo deadweight in Figure G5. The graph indicates that a larger aluminum ship would be more cost effective than the steel ship, but a large aluminum ship cannot properly be compared with a small steel one. This illustrates the problem of "optimizing" ship size for merchant vessels that was discussed earlier in the section "DESIGN OPTIMIZATION."

```
10 "11/16/78",
20 "SAMPLE CALC. -- STEEL SHIP",
30 2,2,1,9,30,25,34,360,36888,11709,200,200,80,1029,1,5,
40 "SEATTLE",
50 1.5,4280,14.8,6,37,0,-1,
60 75,3,-1,0,-1,8,
70 "YOKOMAMA",
80 1.5,4280,16.9,6,33.2,0,
90 75,8,0,-1,-1,9,
100 "ACQUISITION COST",
110 23480000,3,0,1,-1,30,0,1,3,1,
120 "SCRAP VALUE",
130 -530000,5,0,1,0,1,0,1,1,330,
140 "OPERATING COST",
150 1957000,8,0,1,-1,12,0,1,3,1,
```

SAMPLE CALC. -- STEEL SHIP
DATA FILE: DWGEN
11/16/78
EXPENSES FOR YEARS 1 THRU 5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< INCOME >>>>>

PORT	TONS DELIV. PER YEAR	$/TON	ESCAL. %	PRES.VAL. ($1000)
SEATTLE	0	9.44	3.00	0
YOKOMAMA	500503	9.44	3.00	22553
TOTAL	500503			22553

<<<<< EXPENSES >>>>>

ITEM	AVG.ANN. ($1000)	ESCAL. (%)	% OF TOTAL	PRES.VAL. ($1000)	RFR ($)
FUEL AT SEATTLE	1256	8.00	18.17	4099	1.72
FUEL AT YOKOMAMA	0	8.00	.00	0	.00
ACQUISITION COST	2816	3.00	40.74	9199	3.85
SCRAP VALUE	-23	5.00	-.33	-75	-.03
OPERATING COST	2863	3.00	41.42	9342	3.91
TOTAL	6912			22553	9.44

CALCULATED RFR= 9.440003 $/TON AT DATE OF CONTRACT

```
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

SEATTLE
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4280 MILES AT 14.8 KNOTS
     DAYS AT SEA=   12.04955
     FUEL CONSUMED=   445.8330 TONS
CARGO-OFFLOADED=     0 TONS
     -LOADED   =   35593.83 TONS
FUEL-LOADED=   814.1686 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      200 TONS
     FRESH WATER  =      200 TONS
     BALLAST      =        0 TONS
     SERVICE FUEL =      814 TONS
     RESERVE FUEL =       80 TONS
     CARGO        =    35594 TONS
        TOTAL     =    36888 TONS
MAXIMUM DEADWEIGHT=    36888 TONS

YOKOMAMA
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4280 MILES AT 16.9 KNOTS
     DAYS AT SEA=   10.55227
     FUEL CONSUMED=   350.3353 TONS
CARGO-OFFLOADED=   35593.83 TONS
     -LOADED   =     0 TONS
FUEL-LOADED=     0 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      200 TONS
     FRESH WATER  =      200 TONS
     BALLAST      =    10870 TONS
     SERVICE FUEL =      359 TONS
     RESERVE FUEL =       80 TONS
     CARGO        =        0 TONS
        TOTAL     =    11709 TONS
MAXIMUM DEADWEIGHT=    36888 TONS

TOTAL DAYS, ROUND TRIP=   25.60132
AVERAGE NUMBER OF TRIPS PER YEAR= 14.0615
```

FIGURE G- 1 - SAMPLE CALCULATION - STEEL SHIP

```
LIST DWGEN

10 "11/16/73",
20 "SAMPLE CALC. - ALUMINUM SHIP",
30 2,2,1,9,30,30,34,360,
40 39276,14097,200,200,31,1029,1,3,
50 "SEATTLE",
60 1.5,4280,14.3,6,37.0,-1,75,8,-1,0,-1,8,
70 "YOKOHAMA",
80 1.5,4280,16.9,6,33.2,0,75,8,0,-1,-1,8,
90 "ACQUISITION COST",
100 29832000,8,0,1,-1,30,0,1,3,1,
110 "SCRAP VALUE",
120 -2421000,5,0,1,0,1,0,1,1,390,
130 "OPERATING COST",
140 2022000,8,0,1,-1,12,0,1,3,1,
```

```
SAMPLE CALC. - ALUMINUM SHIP
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< INCOME >>>>>
         PORT             TONS DELIV.    $/TON     ESCAL.    PRES.VAL.
                           PER YEAR                  %        ($1000)
     SEATTLE                     0        9.67      8.00           0
     YOKOHAMA               534069        9.67      8.00       24640
         TOTAL              534069                             24640

<<<<< EXPENSES >>>>>
         ITEM               AVG.ANN.  ESCAL.   % OF    PRES.VAL.    RFR
                            ($1000)    (%)     TOTAL   ($1000)      ($)
FUEL AT SEATTLE               1256    8.00    16.63       4099     1.61
FUEL AT YOKOHAMA                 0    8.00      .00          0      .00
ACQUISITION COST              3420    8.00    45.30      11161     4.39
SCRAP VALUE                    -83    5.00    -1.10       -272     -.11
OPERATING COST                2959    8.00    39.17       9652     3.79
         TOTAL                7551                       24640     9.67

CALCULATED RFR=   9.665167 $/TON AT DATE OF CONTRACT
```

```
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

SEATTLE
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4280 MILES AT 14.3 KNOTS
     DAYS AT SEA=   12.04955
     FUEL CONSUMED=   445.3333 TONS
CARGO-OFFLOADED=    0 TONS
     -LOADED    =   37990.83 TONS
FUEL-LOADED=   914.1696 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      200 TONS
     FRESH WATER  =      200 TONS
     BALLAST      =        0 TONS
     SERVICE FUEL =      914 TONS
     RESERVE FUEL =       91 TONS
     CARGO        =    37991 TONS
        TOTAL     =    39276 TONS
MAXIMUM DEADWEIGHT=    39276 TONS

YOKOHAMA
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4220 MILES AT 16.9 KNOTS
     DAYS AT SEA=   10.55227
     FUEL CONSUMED=   350.3352 TONS
CARGO-OFFLOADED=   37930.83 TONS
     -LOADED    =     0 TONS
FUEL-LOADED=     0 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      200 TONS
     FRESH WATER  =      200 TONS
     BALLAST      =    13257 TONS
     SERVICE FUEL =      359 TONS
     RESERVE FUEL =       31 TONS
     CARGO        =        0 TONS
        TOTAL     =    14097 TONS
MAXIMUM DEADWEIGHT=    39276 TONS

TOTAL DAYS, ROUND TRIP=   25.60182
AVERAGE NUMBER OF TRIPS PER YEAR= 14.0615
```

FIGURE G-2 - SAMPLE CALCULATION - ALUMINUM SHIP

```
LIST DWGEN

10 "11/16/79",
20 "SAMPLE CALC. - ALUMINUM SHIP",
30 2,2,1,9,30,30,34,360,
40 36833,13212,200,200,72,1029,1,5,
50 "SEATTLE",
60 1.5,4280,14.8,6,35.5,-1,75,8,-1,0,-1,8,
70 "YOKOHAMA",
80 1.5,4280,16.9,6,31.3,0,75,8,0,-1,-1,8,
90 "ACQUISITION COST",
100 23340000,8,0,1,-1,30,0,1,3,1,
110 "SCRAP VALUE",
120 -2272000,5,0,1,0,1,0,1,1,390,
130 "OPERATING COST",
140 1956000,8,0,1,-1,12,0,1,3,1,
```

```
SAMPLE CALC. - ALUMINUM SHIP
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< INCOME >>>>>
      PORT          TONS DELIV.    $/TON     ESCAL.    PRES.VAL.
                     PER YEAR                  %        ($1000)
     SEATTLE              0         9.95      8.00          0
     YOKOHAMA        500290         9.95      8.00      23761
          TOTAL      500290                             23761

<<<<< EXPENSES >>>>>
          ITEM          AVG.ANN.   ESCAL.   % OF    PRES.VAL.    RFR
                        ($1000)     (%)     TOTAL   ($1000)      ($)
FUEL AT SEATTLE            1205     8.00    16.55      3933     1.65
FUEL AT YOKOHAMA              0     8.00      .00         0      .00
ACQUISITION COST           3249     8.00    44.62     10603     4.44
SCRAP VALUE                 -79     5.00    -1.07      -255     -.11
OPERATING COST             2905     8.00    39.90      9480     3.97
          TOTAL            7282                       23761     9.95

CALCULATED RFR=   9.949787 $/TON AT DATE OF CONTRACT
```

```
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

SEATTLE
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4280 MILES AT 14.8 KNOTS
     DAYS AT SEA=   12.04955
     FUEL CONSUMED= 427.759 TONS
CARGO-OFFLOADED=    0 TONS
     -LOADED    =   35579.68 TONS
FUEL-LOADED=   731.3211 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      200 TONS
     FRESH WATER  =      200 TONS
     BALLAST      =        0 TONS
     SERVICE FUEL =      731 TONS
     RESERVE FUEL =       73 TONS
     CARGO        =    35579 TONS
        TOTAL     =    36833 TONS
• MAXIMUM DEADWEIGHT=  36833 TONS

YOKOHAMA
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4280 MILES AT 16.9 KNOTS
     DAYS AT SEA=   10.55327
     FUEL CONSUMED=   335.5621 TONS
CARGO-OFFLOADED=   35579.68 TONS
     -LOADED    =   0 TONS
FUEL-LOADED=    0 TONS
DEPARTURE WEIGHTS
     CREW & STORES=      200 TONS
     FRESH WATER  =      200 TONS
     BALLAST      =    12339 TONS
     SERVICE FUEL =      345 TONS
     RESERVE FUEL =       78 TONS
     CARGO        =        0 TONS
        TOTAL     =    13212 TONS
MAXIMUM DEADWEIGHT=    36833 TONS

TOTAL DAYS, ROUND TRIP=   25.60182
AVERAGE NUMBER OF TRIPS PER YEAR= 14.0615
```

FIGURE G-2 (CONT.) - SAMPLE CALCULATION - ALUMINUM SHIP
SIMILAR CARGO CAPACITY

```
LIST DWGEN

10 "11/16/78",
20 "SAMPLE CALC. - ALUMINUM SHIP",
30 2,2,1,9,30,30,34,360,
40 41204,14798,200,200,94,1029,1,5,
50 "SEATTLE",
60 1.5,4230,14.3,6,38.2,-1,75,8,-1,0,-1,8,
70 "YOKOHAMA",
80 1.5,4230,16.9,6,34.2,0,75,3,0,-1,-1,9,
90 "ACQUISITION COST",
100 31019000,3,0,1,-1,30,0,1,3,1,
110 "SCRAP VALUE",
120 -2539000,5,0,1,0,1,0,1,1,390,
130 "OPERATING COST",
140 2031000,3,0,1,-1,12,0,1,3,1,
```

```
SAMPLE CALC. - ALUMINUM SHIP
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALYSIS

<<<<< INCOME >>>>>
         PORT           TONS DELIV.   $/TON     ESCAL.    PRES.VAL
                         PER YEAR                 %        ($1000)
     SEATTLE                    0      9.46      9.00            0
     YOKOHAMA              560734      9.46      9.00        25335
         TOTAL             560734                            25335

<<<<< EXPENSES >>>>>
         ITEM              AVG.ANN.  ESCAL.   % OF    PRES.VAL.     RFR
                           ($1000)    (%)    TOTAL    ($1000)       ($)
FUEL AT SEATTLE              1295    3.00    16.67      4225       1.59
FUEL AT YOKOHAMA                0    3.00      .00         0        .00
ACQUISITION COST             3556    3.00    45.31     11605       4.34
SCRAP VALUE                   -87    5.00    -1.13      -285       -.11
OPERATING COST               3000    3.00    39.64      9790       3.66
         TOTAL               7764                      25335       9.46

CALCULATED RFR=   9.464403 $/TON AT DATE OF CONTRACT
```

```
     DATA FILE: DWGEN
     11/16/78
EXPENSES FOR YEARS  1 THRU  5 AFTER DELIVERY USED IN THIS ANALY

SEATTLE
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4290 MILES AT 14.8 KNOTS
     DAYS AT SEA=   12.04955
     FUEL CONSUMED=   450.2928 TONS
CARGO-OFFLOADED=     0 TONS
     -LOADED    =   39890.32 TONS
FUEL-LOADED=    339.1804 TONS
DEPARTURE WEIGHTS
     CREW & STORES=       200 TONS
     FRESH WATER  =       200 TONS
     BALLAST      =         0 TONS
     SERVICE FUEL =       339 TONS
     RESERVE FUEL =        94 TONS
     CARGO        =     39891 TONS
        TOTAL     =     41204 TONS
MAXIMUM DEADWEIGHT=     41204 TONS

YOKOHAMA.
DAYS IN PORT=  1.5
     FUEL CONSUMED=     9 TONS
NEXT LEG OF VOYAGE= 4290 MILES AT 16.9 KNOTS
     DAYS AT SEA=   10.55227
     FUEL CONSUMED=   360.9376 TONS
CARGO-OFFLOADED=   39890.32 TONS
     -LOADED    =     0 TONS
FUEL-LOADED=      0 TONS
DEPARTURE WEIGHTS
     CREW & STORES=       200 TONS
     FRESH WATER  =       200 TONS
     BALLAST      =     13944 TONS
     SERVICE FUEL =       370 TONS
     RESERVE FUEL =        94 TONS
     CARGO        =         0 TONS
        TOTAL     =     14798 TONS
MAXIMUM DEADWEIGHT=     41204 TONS

TOTAL DAYS, ROUND TRIP=    25.60192
AVERAGE NUMBER OF TRIPS PER YEAR= 14.0615
```

FIGURE G-2 (CONT.) - SAMPLE CALCULATION - ALUMINUM SHIP
INCREASED CARGO CAPACITY

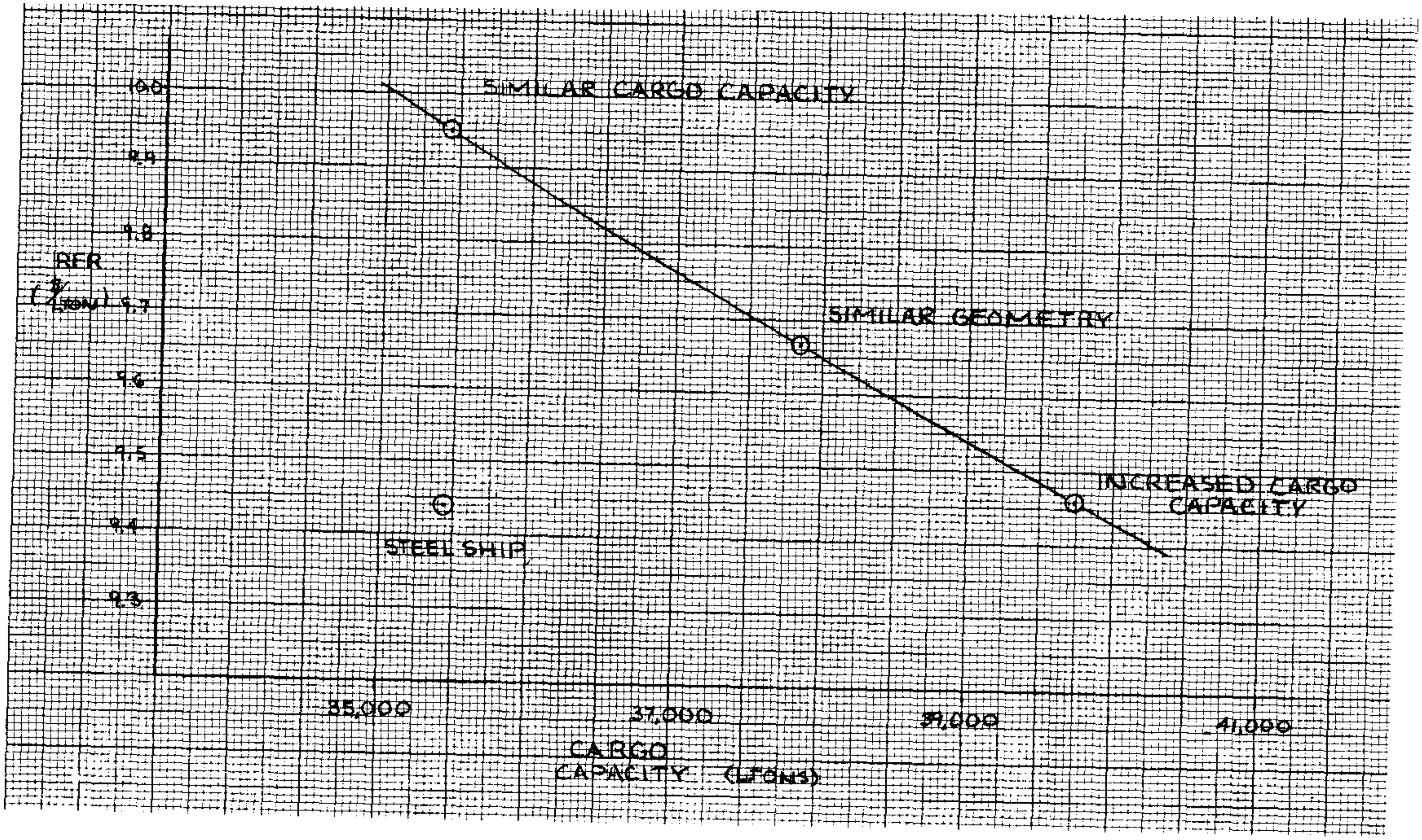


FIGURE G-3 - REQUIRED FREIGHT RATES FOR VARIOUS CARGO TONNAGES

APPENDIX H

SAMPLE NON-ECONOMIC EVALUATION

CONTENTS

MATERIAL TRADE – OFF STUDY
EVALUATION OF NON – ECONOMIC FACTORS

BY D.J. WOOLEY DATE 8/25/78

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
SUSCEPTABILITY TO DAMAGE – MECHANICAL	6	-2	-12	-1	-6	-1	-6
– CHEMICAL	6	-1	-6	-1	-6	-1	-6
– THERMAL	6	-4	-24	-3	-18	-3	-18
– CORROSION	6	+1	+6	+1	+6	+2	+12
POTENTIAL EFFECTS OF DAMAGE	6	+1	+6	+1	+6	+2	+12
AVAILABILITY OF REPAIR FACILITIES	5	-6	-30	-5	-25	-5	-25
COMPATIBILITY WITH INTENDED CARGO	10	-1	-10	-1	-10	0	—
COMPATIBILITY WITH INTENDED OPERATING LOCATION	10	0	—	0	—	0	—
HYDRODYNAMIC CHARACTERISTICS	4	0	—	0	—	0	—
APPEARANCE	2	+1	+2	+3	+6	+4	+8
TOTAL	61		-68		-.47		-23
FACTOR RATINGS		-.111		-.077		-.038	

RATINGS FOR THIS FACTOR = $\dfrac{\sum \text{WEIGHTED VALUES}}{10 \cdot \sum \text{WEIGHTS}}$

FIGURE H-1 - SUITABILITY FOR INTENDED USE

MATERIAL TRADE – OFF STUDY
EVALUATION OF NON – ECONOMIC FACTORS

BY D. J. WOOLEY DATE 8/25/78

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
EFFECT ON LAND – DURING PRODUCTION OF RAW MATERIALS	5	0	–	+2	+10	+3	+15
– DURING CONSTRUCTION/REPAIR/SCRAPPING	5	0	–	0	–	0	–
– DURING OPERATIONS	6	0	–	0	–	0	–
EFFECT ON WATER – DURING PRODUCTION OF RAW MATERIALS	4	0	–	0	–	0	–
– DURING CONSTRUCTION/REPAIR/SCRAPPING	4	0	–	0	–	0	–
– DURING OPERATIONS	5	0	–	0	–	0	–
EFFECT ON AIR – DURING PRODUCTION OF RAW MATERIALS	2	0	–	+2	+4	+2	+4
– DURING CONSTRUCTION/REPAIR/SCRAPPING	2	0	–	0	–	+1	+2
– DURING OPERATIONS	3	0	–	0	–	0	–
EFFECT ON WILDLIFE – DURING PRODUCTION OF RAW MATERIALS	1	0	–	0	–	+1	+1
– DURING CONSTRUCTION/REPAIR/SCRAPPING	1	0	–	0	–	0	–
– DURING OPERATIONS	2	0	–	0	–	0	–
EFFECT ON PEOPLE – DURING PRODUCTION OF RAW MATERIALS	8	0	–	+1	+8	+1	+8
– DURING CONSTRUCTION/REPAIR/SCRAPPING	8	0	–	0	–	+1	+8
– DURING OPERATIONS	10	0	–	0	–	0	–
TOTAL	66		0		+22		+38
FACTOR RATINGS		0		+.033		+.058	

$$\text{RATING FOR THIS FACTOR} = \frac{\Sigma \text{ WEIGHTED VALUES}}{10 * \Sigma \text{ WEIGHTS}}$$

FIGURE H-2 - ENVIRONMENTAL IMPACT

MATERIAL TRADE – OFF STUDY
EVALUATION OF NON – ECONOMIC FACTORS

BY D. J. WOOLEY DATE 8/25/78

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
MATERIALS	10	-2	-20	0	–	0	–
ENERGY	10	-2	-20	-2	-20	-1	-10
MANPOWER – SKILLED	4	-1	-4	-1	-4	0	–
– UNSKILLED	2	0	–	0	–	+1	+2
PRODUCTION FACILITIES	4	-1	-4	0	–	+1	+4
TRANSPORTATION FACILITIES	1	0	–	+1	+1	+1	+1
BALANCE OF TRADE (IMPORT/EXPORT)	4	0	–	0	–	0	–
TOTAL	35		-48		-23		-3
FACTOR RATINGS		-.137		-.066		-.009	

$$\text{RATING FOR THIS FACTOR} = \frac{\Sigma \text{ WEIGHTED VALUES}}{10 \cdot \Sigma \text{ WEIGHTS}}$$

FIGURE H-3 - USE OF NATIONAL RESOURCES

MATERIAL TRADE – OFF STUDY
EVALUATION OF NON – ECONOMIC FACTORS

BY D. S. WOOLEY DATE 8/25/78

ATTRIBUTE	WEIGHT	PESSIMISTIC		MOST. PROB.		OPTIMISTIC	
		VALUE	WTD. VAL.	VALUE	WTD. VAL.	VALUE	WTD. VAL.
DEVELOPMENT OF RULES/REGULATIONS	1	-6	-6	-5	-5	-4	-4
DEVELOPMENT OF INTERNATIONAL AGREEMENTS	1	0	–	0	–	0	–
SUBSIDY – CONSTRUCTION	10	0	–	+1	+10	+2	+20
– OPERATING	10	0	–	0	–	+1	+10
LOAN GUARANTEES	10	0	–	+1	+10	+2	+20
INSURANCE (IF NOT AVAILABLE COMMERCIALLY)	10	0	–	0	–	+1	+10
TOTAL	42		-6		+15		+56
FACTOR RATINGS		-.014		+.036		+.133	

$$\text{RATING FOR THIS FACTOR} = \frac{\Sigma \text{ WEIGHTED VALUES}}{10 * \Sigma \text{WEIGHTS}}$$

FIGURE H-4 - GOVERNMENT INVOLVEMENT

MATERIAL TRADE – OFF STUDY
EVALUATION OF NON – ECONOMIC FACTORS

BY D. J. WOOLEY DATE 8/25/78

ATTRIBUTE	WEIGHT	PESSIMISTIC VALUE	PESSIMISTIC WTD. VAL.	MOST. PROB. VALUE	MOST. PROB. WTD. VAL.	OPTIMISTIC VALUE	OPTIMISTIC WTD. VAL.
TECHNICAL – UNFORESEEN PROBLEMS IN DESIGN	6	-3	-18	-1	-6	-1	-6
– UNFORESEEN PROBLEMS IN CONSTRUCTION	10	-4	-40	-2	-20	-2	-20
– UNFORESEEN PROBLEMS IN MAINTENANCE/REPAIR	8	-2	-16	-2	-16	-2	-16
– UNFORESEEN PROBLEMS IN OPERATION	8	0	–	0	–	0	–
FINANCIAL – CHANGES IN CONSTRUCTION COST ESTIMATES	10	-2	-20	-2	-20	-2	-20
– CHANGES IN MAINTENANCE/REPAIR COST ESTIMATES	8	-1	-8	-1	-8	0	–
– CHANGES IN OPERATING COST ESTIMATES	8	0	–	0	–	0	–
– CHANGES IN FINANCING/INSURANCE COST ESTIMATES	4	0	–	0	–	0	–
REGULATORY – UNFORESEEN CHANGES IN REQUIREMENTS	3	0	–	0	–	0	–
– LIMITATIONS ON HARBOR ENTRY	1	0	–	+1	+1	+1	+1
AVAILABILITY OF CREW	2	0	–	0	–	+1	+2
SUITABILITY FOR ALTERNATE CARGOES	1	-1	-1	0	–	0	–
SUITABILITY FOR ALTERNATE OPERATING LOCATIONS	1	0	–	+2	+2	+2	+2
TOTAL	70		-103		-67		-57
FACTOR RATINGS		-.147		-.096		-.081	

$$\text{RATING FOR THIS FACTOR} = \frac{\sum \text{WEIGHTED VALUES}}{10 * \sum \text{WEIGHTS}}$$

FIGURE H-5 - RISK

APPENDIX J

SAMPLE COMBINED EVALUATION

CONTENTS

Page No.

MATERIAL TRADE-OFF STUDY

BY Daniel Wooley DATE 8/25/78

ECONOMIC FACTOR	($/TON)
BASE SHIP RFR	9.440
NEW MATERIAL SHIP RFR	9.665
ECONOMIC WORTH	–.225

NON – ECONOMIC FACTORS	MULTI-PLIER ($/TON)	PESSIMISTIC		MOST PROBABLE		OPTIMISTIC	
		RATING	WORTH ($/TON)	RATING	WORTH ($/TON)	RATING	WORTH ($/TON)
SUITABILITY FOR INTENDED USE	.65	–.111	–.072	–.077	–.050	–.038	–.025
ENVIRONMENTAL IMPACT	.30	0	–	+.033	+.010	+.058	+.017
USE OF NATIONAL RESOURCES	.01	–.137	–.001	–.066	–.001	–.009	0
GOVERNMENT INVOLVEMENT	.50	–.014	–.007	+.036	+.018	+.133	+.067
RISK	.70	–.147	–.103	–.096	–.067	–.081	–.057
NON – ECONOMIC WORTH			–.183		–.090		+.002

TOTAL WORTH	WORTH ($/TON)	% OF BASE SHIP RFR
PESSIMISTIC EVALUATION	–.408	–4.3
MOST PROBABLE EVALUATION	–.315	–3.3
OPTIMISTIC EVALUATION	–.223	–2.4

FIGURE J-1 - FINAL EVALUATION OF SAME GEOMETRY ALUMINUM SHIP

MATERIAL TRADE-OFF STUDY

BY Daniel Wooley DATE 8/25/78

ECONOMIC FACTOR	($/TON)
BASE SHIP RFR	9.440
NEW MATERIAL SHIP RFR	9.950
ECONOMIC WORTH	–510

NON – ECONOMIC FACTORS	MULTI-PLIER ($/TON)	PESSIMISTIC		MOST PROBABLE		OPTIMISTIC	
		RATING	WORTH ($/TON)	RATING	WORTH ($/TON)	RATING	WORTH ($/TON)
SUITABILITY FOR INTENDED USE	.65	–.111	–.072	–.077	–.050	–.038	–.025
ENVIRONMENTAL IMPACT	.30	0	–	+.033	+.010	+.058	+.017
USE OF NATIONAL RESOURCES	.01	–.137	–.001	–.066	–.001	–.009	0
GOVERNMENT INVOLVEMENT	.50	–.014	–.007	+.036	+.018	+.133	+.067
RISK	.70	–.147	–.103	–.096	–.067	–.081	–.057
NON – ECONOMIC WORTH			–.183		–.090		+.002

TOTAL WORTH	WORTH ($/TON)	% OF BASE SHIP RFR
PESSIMISTIC EVALUATION	–.693	–7.3
MOST PROBABLE EVALUATION	–.600	–6.4
OPTIMISTIC EVALUATION	–.508	–5.4

FIGURE J-2 - FINAL EVALUATION OF SAME CAPACITY ALUMINUM SHIP

MATERIAL TRADE-OFF STUDY

BY Daniel Wooley DATE 8/25/78

ECONOMIC FACTOR	($/TON)
BASE SHIP RFR	9.440
NEW MATERIAL SHIP RFR	9.464
ECONOMIC WORTH	–.024

NON – ECONOMIC FACTORS	MULTIPLIER ($/TON)	PESSIMISTIC		MOST PROBABLE		OPTIMISTIC	
		RATING	WORTH ($/TON)	RATING	WORTH ($/TON)	RATING	WORTH ($/TON)
SUITABILITY FOR INTENDED USE	.65	–.111	–.072	–.077	–.050	–.038	–.025
ENVIRONMENTAL IMPACT	.30	0	–	+.033	+.010	+.058	+.017
USE OF NATIONAL RESOURCES	.01	–.137	–.001	–.066	–.001	–.009	0
GOVERNMENT INVOLVEMENT	.50	–.014	–.007	+.036	+.018	+.133	+.067
RISK	.70	–.147	–.103	–.096	–.067	–.081	–.057
NON – ECONOMIC WORTH			–.183		–.090		+.002

TOTAL WORTH	WORTH ($/TON)	% OF BASE SHIP RFR
PESSIMISTIC EVALUATION	–.207	–2.2
MOST PROBABLE EVALUATION	–.114	–1.2
OPTIMISTIC EVALUATION	–.022	–0.2

FIGURE J-3 – FINAL EVALUATION OF INCREASED CAPACITY ALUMINUM SHIP

SHIP RESEARCH COMMITTEE
Maritime Transportation Research Board
National Academy of Sciences-National Research Council

****

The Ship Research Committee has technical cognizance of the interagency Ship Structure Committee's research program:

Mr. O. H. Oakley, Chairman, *Consultant, McLean, VA*
Mr. M. D. Burkhart, *Naval Oceanography Division, Department of the Navy, Washington, D.C.*
Dr. J. N. Cordea, *Senior Staff Metallurgist, ARMCO INC., Middletown, OH*
Mr. D. P. Courtsal, *Vice President, DRAVO Corporation, Pittsburgh, PA*
Mr. W. J. Lane, *Consultant, Baltimore, MD*
Mr. A. C. McClure, *Alan C. McClure Associates, Inc., Houston, TX*
Dr. W. R. Porter, *Vice Pres. for Academic Affairs, State Univ. of N.Y. Maritime College*
Prof. S. T. Rolfe, *Civil Engineering Dept., University of Kansas*
Mr. R. W. Rumke, *Executive Secretary, Ship Research Committee*

****

The Ship Materials, Fabrication, & Inspection Advisory Group prepared the project prospectus, evaluated the proposals for this project, provided the liaison technical guidance, and reviewed the project reports with the investigator:

Dr. J. N. Cordea, Chairman, *Senior Staff Metallurgist, ARMCO INC., Middletown, OH*
Mr. W. C. Brayton, *Asst. to General Manager, Bethlehem Steel Corp., Sparrows Point, MD*
Mr. T. E. Koster, *Naval Architect, AMOCO International Oil Co., Chicago, IL*
Dr. W. C. Leslie, *Dept. of Materials & Met. Engrg., Univ. of Michigan, Ann Arbor, MI*
Dr. H. I. McHenry, *Cryogenics Division, National Bureau of Standards, Boulder, CO*
Mr. P. W. Marshall, *Senior Staff Civil Engr., SHELL OIL CO., Houston, TX*
Prof. P. F. Packman, *C'man, Dept. of Civil & Mech. Engrg., Southern Methodist Univ. Dallas, TX*
Prof. G. C. Sih, *Inst. of Fracture & Solid Mechanics, Lehigh Univ., Bethlehem, PA*

****

SHIP STRUCTURE COMMITTEE PUBLICATIONS

These documents are distributed by the National Technical Information Service, Springfield, Va. 22151. These documents have been announced in the Clearinghouse journal U. S. Government Research & Development Reports (USGRDR) under the indicated AD numbers.

SSC-275, *The Effect of Strain Rate on the Toughness of Ship Steels* by P. H. Francis, T. S. Cook, and A. Nagy. 1978. AD-A059453.

SSC-276, *Fracture Behavior Characterization of Ship Steels and Weldments* by P. H. Francis, T. S. Cook, and A. Nagy. 1978. AD-A058939.

SSC-277, *Original Radar and Standard Tucker Wavemeter SL-7 Containership Data Reduction and Correlation Sample* by J. F. Dalzell. 1978. AD-A062394.

SSC-278, *Wavemeter Data Reduction Method and Initial Data for the SL-7 Containership* by J. F. Dalzell. 1978. AD-A062391.

SSC-279. *Modified Radar and Standard Tucker Wavemeter SL-7 Containership Data* by J. F. Dalzell. 1978. AD-A062393.

SSC-280, *Results and Evaluation of the SL-7 Containership Radar and Tucker Wavemeter Data* by J. F. Dalzell. 1978. AD-A062392.

SSC-281, *Bibliography for the Study of Propeller-Induced Vibration in Hull Structural Elements* by O. H. Burnside and D. D. Kana. 1978. AD-A062996.

SSC-282, *Comparison of Stresses Calculated Using the DAISY System to Those Measured on the SL-7 Containership Program* by H. Y. Jan, K. T. Chang, and M. E. Wojnarowski. 1979. AD-A069031

SSC-283, *A Literature Survey on the Collision and Grounding Protection of Ships* by N. Jones. 1979. AD-A069032

SSC-284, *Critical Evaluation of Low-Energy Ship Collision-Damage Theories and Design Methodologies - Volume I - Evaluation and Recommendations* by P. R. Van Mater, Jr., and J. G. Giannotti. 1979. AD-A070567

SSC-285, *Critical Evaluation of Low-Energy Ship Collision-Damage Theories and Design Methodologies - Volume II - Literature Search and Review* by P. R. Van Mater, Jr., and J. G. Giannotti. 1979. AD-A070568

SSC-286, *Results of the First Five "Data Years" of Extreme Stress Scratch Gauge Data Collection Aboard Sea-Land's SL-7's* by R. A. Fain and E. T. Booth. 1979.

SSC-287, *Examination of Service and Stress Data of Three Ships for Development of Hull Girder Load Criteria* by J. F. Dalzell, N. M. Maniar, and M. W. Hsu. 1979.

SSC-288, *The Effects of Varying Ship Hull Proportions and Hull Materials on Hull Flexibility Bending and Vibratory Stresses* by P. Y. Chang. 1979.