Contract No. E(04-3)-1175

MASTER

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June 2, 1977

DRAFT REPORT
ENERGY USE IN THE MARINE TRANSPORTATION INDUSTRY
TASK III - EFFICIENCY IMPROVEMENTS

for

Division of Transportation Energy Conservation
Non-Highway Transport Systems
Energy Research and Development Administration
20 Massachusetts Avenue
Washington, D.C. 20545

1175 8-1

BOOZ · ALLEN & HAMILTON Inc.

Management Consultants

4733 BETHESDA AVENUE
BETHESDA, MARYLAND 20014
656-2200
AREA CODE 301

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4733 BETHESDA AVENUE
BETHESDA, MARYLAND 20014
656-2200
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June 2, 1977
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Mr. Richard Alpaugh
Division of Transportation
Energy Conservation
Non-Highway Transport Systems
Energy Research and
Development Administration
20 Massachusetts Avenue, N.W.
Washington, D.C. 20545

Subject: Draft Report Task III - Energy Use in the Marine Transportation Industry - Efficiency Improvements

Dear Dick:

We are pleased to submit our draft Task III report entitled, "Energy Use in the Marine Transportation Industry - Efficiency Improvements." We are enclosing seven copies for your use. Three copies have been forwarded to Ms. E. Romo in ERDA Oakland as required by the contract.

If you have any questions concerning this report or the conclusions reached as a result of the analysis please do not hesitate to call Mr. Leo Donovan or myself at (301) 656-2200.

Very truly yours,

BOOZ·ALLEN & HAMILTON Inc.

John G. Blackburn
Project Manager

Approved:

Leo J. Donovan
Research Director

cc: E. Romo, ERDA, Oakland, California

Enclosures

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I N D E X   O F   T A B L E S

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I. INTRODUCTION AND EXECUTIVE SUMMARY

I. INTRODUCTION AND EXECUTIVE SUMMARY

This report covers the work accomplished under the third task of a four-task assignment, entitled "Energy Study of Ship Transportation Systems." This third task identifies and evaluates those research and development areas that hold promise for maritime energy conservation. The scope of the entire assignment is:

- Task I — Industry Summary — to define energy use patterns in the commercial maritime transportation industry
- Task II — Regulations and Tariffs — to define the regulatory structure surrounding the commercial marine transportation sector and evaluate the energy impact of various regulations
- Task III — Efficiency Improvements — to identify conservation-related research and development programs and evaluate their impacts in terms of costs, energy savings potential, and technological risk
- Task IV — Industry Future — to define future scenarios which offer energy savings potential and evaluate the cost and energy use implications of each and recommend specific courses of action to be pursued by ERDA.

The approach used in Task III is discussed in the following section.

1. METHODOLOGY USED IN THE EVALUATION OF POTENTIAL RESEARCH AND DEVELOPMENT AREAS

The methodology used to identify and evaluate the potential R&D programs consisted of:

- Literature search centering on research publications of various public and private agencies

- Interviews with selected marine-oriented research and development organizations
- Data reduction and evaluation of potential programs.

During the course of this assignment interviews were conducted with individuals from:

- Energy Research and Development Administration
- Department of Commerce - Maritime Administration
- Maritime Research Center - Kings Point, New York
- U.S. Navy - Office of Naval Research
- U.S. Navy - Naval Ship Research and Development Center
- Webb Institute of Naval Architecture
- Society of Naval Architects and Marine Engineers
- United States Naval Academy
- Private organizations conducting research and and development in this area.

The economic and energy impact and technological risk analysis consisted of five steps:

- Step 1 — Identify potential program areas and applications for each from among the generic ships contained in the Maritime Transportation Energy Model* (MTEM)
- Step 2 — Calculate changes in first costs and operation expenses associated with the introduction of each program area into the existing U.S. flag fleet and determine the impact on required freight rate
- Step 3 — Calculate the potential energy impact associated with the introduction of each program area

* "Maritime Energy Transportation Model," developed in conjunction with ERDA contract E(04-3)-1175.

- Step 4 — Determine the degree of technological risk associated with each program area

- Step 5 — Estimate costs of ERDA program actions in each of the program areas.

In an earlier task, the productivity and energy consumption of the existing marine transportation industry was developed, as shown in Table I-1.* The results of this effort were used as a baseline against which the impacts of proposed programs were evaluated.

Table I-1
Productivity and Energy Consumption Summary of the Marine Transportation Industry

Sector	Population	Long Tons of Cargo Moved (Millions)	Energy Consumed (quads)	Percent of Total Energy Consumed
Ocean	4,800	654.9	2.360	80.0
Great Lakes	690	175.3	0.052	1.8
Inland Waterways	2,400	535.8	0.09	3.0
Coastal	1,930	213.0	0.112	4.0
Offshore	620	–	0.064	2.2
Pleasure Craft	7,400,000	–	0.241	8.2
Fishing & Misc.	90,300	–	0.032	0.8
Total	7,500,740	1,579	2.951	100.0

Foreign and domestic trade data for 1974, the latest year available, in terms of tons of cargo moved and the U.S. and foreign flag fleet that provided the transportation

* Draft report "Energy Use in the Marine Transportation Industry," Task I - Industry Summary, January 11, 1977, ERDA contract No. E(04-3)-1175.

services, were used to develop a baseline case for the Maritime Transportation Energy Model, (MTEM). Each of the program areas identified during the course of this assignment were simulated in the existing U.S. flag fleet by changing the appropriate baseline operating and cost parameters. The economic and energy impacts were then calculated. A sample output from this model is shown in Appendix G.

2. SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The technology base of the commercial marine transportation industry relating to energy usage, is made up of five generic technologies:

- Main propulsion plants
- Propulsors
- Hydrodynamics
- Vessel operations
- Fuels.

This study identified 15 specific program areas in four of these generic technologies, as shown in Table I-2. Programs in the area of marine fuels are being evaluated under separate contracts.

Table I-2
The Fifteen Maritime Energy Conservation Program Areas Identified and Evaluated

Generic Technology	Program Area
Main Propulsion Plants	High Pressure/Temperature Reheat Steam (HPTRS)
	Slow Speed Diesels (SSD)
	Diesel Bottoming Cycles (DBC)
	Adiabatic Diesels (AD)
	Naval Academy Heat Balance Engine (NAHBE)
	Heavy Duty Gas Turbines & Combined Cycles (GTCC)
	Closed Cycle Gas Turbines (CCGT)
Propulsors	Contra-rotating Propellers (CR)
	Propellers in Nozzles (KORT)
Hydrodynamics	Submerged Air Cushions (SAC)
	Cutaway Hulls (CH)
	Tunnel Sterns (TS)
	Hull Maintenance & Smoothing (HMS)
Vessel Operations	Vessel Routing (VR)
	Vessel Operations (VO)

An economic and energy impact analysis and technological risk assessment was performed on the specific program areas and the results are summarized in Table I-3. Two general conclusions were drawn:

- All programs identified show a net economic benefit when applied to the current U.S. merchant fleet

- Thirteen of the fifteen program areas have energy consumption reduction potentials between 0 and 5 percent of the total U.S. flag fleets energy requirements

Based on the results summarized in Table I-3, three recommendations were made.

Table I-3
Results of Economic and Energy
Impact Analysis

Level of Technological Risk	Program Area	Range of Reduction in Required Freight Rate (%)		Energy Conservation Potential (% of U.S. Flag Consumption)	Potential Program Start	Program Duration (Years)	Estimated Funding Requirements (Millions of $)
		Minimum	Maximum				
Low	SSD	1.7	8.6	5.5	FY-78	2	0.500
Low	VO	0.3	2.1	1.4	FY-78	-	NONE
Low	VR	0.0	0.0	0.0	FY-78	-	NONE
Medium	DBC	6.7	10.2	3.6	FY-78	2	3.000
Medium	HMS	0.4	5.5	3.1	FY-78	1	0.250
Medium	GTCC	0.8	9.7	1.2	FY-78	2-3	4.000
Medium	TS	0.2	2.3	0.6	FY-78	1	0.300
Medium	CR	1.8	3.4	0.5	FY-78	2-3	4.000
Medium	HPTRS	4.5	9.3	0.4	FY-78	10	3.000
Medium	KORT	0.9	0.9	0.0	FY-78	2-3	1.000
Medium	CH	0.1	0.1	0.0	FY-78	1	0.300
High	AD	7.5	18.3	10.2	FY-80	5	2.000
High	NAHBE	5.6	6.7	5.4	FY-79	3	1.000
High	CCGT	6.4	11.4	1.4	FY-80	6-7	50.000
High	SAC	1.9	1.9	0.0	FY-78	1	0.400

(1) <u>Three Program Areas Are Recommended for Funding in FY78</u>

Based on the energy savings potentials calculated, the programs relating to:

- Slow-speed diesels
- Diesel bottoming cycles
- Hull maintenance and smoothing

are recommended for funding in FY78. The specific program elements for each of these programs are identified in the appendices.

(2) Three High Risk Program Areas Should Be Reevaluated in the Future

The results of the energy impact analysis identified three high risk technologies:

- Adiabatic diesels
- Naval Academy heat balance engine
- Closed cycle gas turbines

that are presently being supported by ERDA, the U.S. Navy, and the U.S. Army. Should the projected potentials of these research projects be realized, they should be evaluated for marine applications. Specific dates for reevaluation are given in Table I-3.

(3) Four Program Areas Are Recommended for Action in FY78 in Anticipation of Cargo Preference Legislation

In the event that Congress passes cargo preference legislation reserving 20 to 30 percent of all oil imports for U.S. flag tankers, four program areas:

- Tunnel sterns
- Propellers in nozzles
- Cutaway hulls
- Submerged air cushions

offer significant energy savings potential. The energy savings potential for these programs, shown in Table I-3 are based on current U.S. flag participation in the petroleum import trade, which understates the potential future applications of these programs.

* * * * *

The remainder of this report is divided into two chapters and seven appendices. Chapter II details the methodology used in the analysis and Chapter III presents the results, conclusions, and recommendations. The first five appendices (A through E) each addresses one of the generic technologies identified above. The sixth appendix (F) contains the baseline operating and cost parameters against which the 15 program areas were evaluated, and the last appendix, (G), contains sample printouts of the MTEM model used to evaluate the energy consumption and economic impacts associated with the candidate technology areas.

II. APPROACH AND ANALYSIS

II. APPROACH AND ANALYSIS

The technology base of the commercial marine transportation industry relating to energy useage is composed of five generic technology areas:

- Main propulsion plants
- Propulsors
- Hydrodynamics
- Vessel operations
- Fuels.

The analysis described in this chapter focuses on the identification and evaluation of programs in the first four areas. Programs addressing alternative and contingency fuels for the commercial maritime transportation industry are the subject of two other studies and are discussed only briefly in this report.

Fifteen existing and proposed research and development program areas were identified in the four generic technology areas. Due to the diversity of vessel types and operational profiles that exist in the commercial marine transportation industry, none of the programs identified has across-the-board applications. As a result, the economic and energy impact and technology risk assessment was structured around five separate steps:

- Step 1—Identify potential program areas and applications for each from among the generic ships contained in the maritime transportation energy model
- Step 2—Determine changes in first costs and operational expenses associated with the introduction of each program area into the existing U.S. flag fleet and determine the impact on required freight rates
- Step 3—Calculate the energy impact associated with the introduction of each program area
- Step 4—Determine the category of technological risk associated with each program area

- Step 5 — Estimate costs of ERDA program actions in each of the program areas.

Key to the analysis in steps one through three is the use of the Marine Transportation Energy Model (MTEM) developed in Task I. This model simulates the United States' maritime transportation industries activities for one year. Cargo movements, for the year 1974, are specified for 27 foreign and 16 domestic trade routes. A series of 35 generic vessels was developed and are contained in the model. Each of these vessels is described in terms of application to trade routes speed, horsepower, fuel consumption, cargo carring capacity, acquisition and operating costs as shown in Appendix F.

Each program area to be analyzed can be introduced into this generic U.S. flag fleet by varing the appropriate operating parameters. The operations of this "new" fleet were then simulated with the model and changes in the energy consumption patterns and economic performance determined. Typical results of the computerized analysis are shown in Appendix G.

1. STEP 1 — FIFTEEN PROGRAM AREAS WERE IDENTIFIED AND THEIR AREA OF APPLICATIONS DETERMINED

Fifteen program areas were identified in the four generic technology categories:

- Main Propulsion Plants
  - High pressure/temperature reheat steam plants (HPTRS)
  - Slow speed diesels (SSD)
  - Diesel bottoming cycles (DBC)
  - Adiabatic diesels (AD)
  - Heavy duty gas trubines and combined cycles (GTCC)
  - Closed cycle gas turbines (CCGT)
- Propulsors
  - Contra-rotating propellers (CR)
  - Propellers in nozzels (KORT)

- Hydrodynamics
  - Submerged air cushions (SAC)
  - Cutaway hulls (CH)
  - Tunnel sterns (TS)
  - Hull maintenance and smoothing (HMS)
- Vessel Operations
  - Vessel routing (VR)
  - Vessel operations (VO)

These fifteen program areas were then applied to the series of 35 generic vessels described in Appendix F. Table II-1 identifies the application of each program area to industry sector and generic vessel type.

The applicability of each program area was based on a consideration of:

- Vessel type
- Operational profiles
- Current industry practice
- Weight or space limitations
- Power ranges

These considerations are discussed in the appendices that address each program area. Each program area is briefly discussed in the following sections.

(1) High Pressure/Temperature Reheat Steam Plants (HPTRS)

Reheat steam main propulsion plants offer a potential for energy conservation. The current state-of-the-art will allow production of reheat steam plants with steam conditions of 1450 PSIG and 950°F with one stage of reheat to 950°F. Fuel rates ranging from .46 lb/SHP-Hr to .41 lb/SHP-Hr of residual fuel are possible with this type of plant.

Reheat steam plants with initial steam conditions of 2400 PSIG and 1050°F with one stage of reheat to 1050°F are now being proposed. Fuel rates of .42 lb/SHP-Hr to .37 lb/SHP-Hr using residual fuel are possible with these plants. As shown in table II-1 the 2400 PSIG/1050°F/1050°F reheat steam plants were applied to all generic U.S. flag vessels having installed Horsepower levels greater than 30,000 SHP. A more detailed discussion of this program area is contained in Appendix A.

Table II-1
Application of Program Areas to Industry Sector and Generic Vessel Types

Industry Sector	Vessel Type	DWT	HP	Speed Knots (mph)	Main Propulsion Plants							Propulsors		Hydrodynamics				Vessel Operations	
					HPTRS	SSD	DBC	AD	NAHBE	GTCC	CCGT	CR	KORT	SAC	CH	TS	HMS	VR	VO
Foreign Trade	Container	12,000	8,000	16													●	●	●
	Container	16,500	17,000	20		●				●							●	●	●
	Container	18,500	18,000	20		●				●							●	●	●
	Container	23,000	28,000	23		●				●	●	●					●	●	●
	Ro/Ro	10,000	11,000	24															
	Ro/Ro	16,500	22,000	22.5						●	●	●					●	●	●
	Ro/Ro	18,000	25,000	22.5															
	Barge	33,000	33,000	22	●					●	●	●					●	●	●
	Carriers	42,000	42,000	22	●					●	●	●					●	●	●
	Break Bulk	13,500	14,500	19		●											●	●	●
	Tramp	8,400	5,000	14													●	●	●
	Dry Bulk	20,000	8,000	15												●	●	●	●
	Dry Bulk	30,000	10,000	15												●	●	●	●
	Dry Bulk	40,000	11,000	15												●	●	●	●
	Tanker	20,000	7,000	14												●	●	●	●
	Tanker	40,000	9,000	14												●	●	●	●
	Tanker	65,000	14,000	15		●										●	●	●	●
	Tanker	80,000	16,000	15		●				●						●	●	●	●
	Tanker	150,000	20,000	15	●	●				●			●	●	●	●	●	●	●
Inland Rivers	Tow Boat		1,350	(7.2)			●	●	●										
Coastal	Tanker	40,000	12,000	15		●										●	●		●
	Tug		2,000	8			●	●	●										
	Freighter	7,800	6,000	15.5															●
Great Lakes	Tug		900	(9)			●	●	●										
	Dry Bulk	16,700	4,860	(12)															
	Dry Bulk	14,900	4,180	(12)			●	●											
	Dry Bulk	13,100	2,550	(12)															
	Tanker	6,576	1,925	(12)															
	Tanker	2,676	1,410	(12)			●	●	●										
Offshore	Tug		4,000	14			●	●	●										
	Tug/supply		3,300	15			●	●	●										
	Supply		3,300	13			●	●	●										
	Crewboat		1,800	25			●	●	●										
Pleasure	None							●	●										
Fishing & Misc.	None							●	●										

(2) Slow Speed Diesels (SSD)

Slow speed diesels are the predominant choice for main propulsion plants worldwide. The primary advantage offered by slow speed diesels is their low brake specific fuel consumption of .35 to .37 lb/BHP-Hr of residual fuel. Until recently, this type of main propulsion plant was not available in the United States. Slow speed diesels were applied to all generic U.S. flag vessels having installed horsepower levels greater than 12,000 SHP. A more detailed description of this program area is contained in Appendix A.

(3) Diesel Bottoming Cycles (DBC)

Diesel bottoming cycles offer a potential for energy conservation through the recovery of energy lost through the exhaust gases and cooling water. The energy recovery potential of diesel bottoming cycles is on the order of 15 to 18 percent. Diesel bottoming cycles were applied to all generic U.S. flag vessels that currently use medium speed diesels for their main propulsion plants A more detailed description of this area is contained in Appendix A.

(4) Adiabatic Diesels (AD)

The adiabatic diesel is a engine with true adiabatic (constant heat) compression of the fuel air mixture in a diesel cycle. The potential for energy conservation of this program is a brake specific fuel consumption of .28 lb/BHP-Hr of diesel fuel. Adiabatic diesels were applied to all generic U.S. flag vessels that currently use medium-speed diesels for their main propulsion plants. A more detailed description of this program area is contained in Appendix A.

(5) Naval Academy Heat Balance Engine (NAHBE)

The Naval Academy heat balance engine is based on nonadiabatic compression of the fuel air mixture in an Otto cycle. The concept is based on using retained heat and shock waves to enhance the combustion process. Improvements in the thermal efficiency of an internal combustion engine of 10 percent at full load have been claimed. The Naval Academy heat balance engine was applied to all generic U.S. flag vessels that currently use medium-speed diesels for their main propulsion plants and have installed horsepower levels of less than 4000 BHP. A more detailed description of this program area is contained in Appendix A.

(6) Heavy Duty Gas Turbines and Combined Cycles (GTCC)

Marine applications of industrial type heavy duty gas turbines capable of burning heavy residual fuels have recently been developed and installed in a few ocean going vessels. Use of heavy duty gas turbines with steam bottoming cycles have a potential for specific fuel consumption rates of .40 lb/SHP-Hr to .36 lb/SHP-Hr. Heavy duty gas turbine and combined cycles were applied to all generic U.S. flag vessels whose installed horsepower level was greater than 45,000 SHP and all Ro/Ro vessels irregardless of horsepower level. A more detailed description of this program area is contained in Appendix A.

(7) Closed Cycle Gas Turbines (CCGT)

Closed cycle gas turbines differ from the open cycles in that the combustion gases are not used in the power cycle. They are used to heat a working fluid that is expanded through a power turbine. This gives the closed cycle gas turbine a true multifuel capability. Specific fuel consumption rates of .36 to .35 lb/SHP-Hr of residual fuel are currently within the state-of-the-art. Closed cycle gas turbines were applied to all generic U.S. flag vessels having installed horsepower levels greater than 20,000 SHP. A more detailed discussion of this program area is contained in Appendix A.

(8) Contra-rotating Propellers (CR)

Contra-rotating propellers are two propellers, one located directly behind the other but rotating in the opposite direction. Increases in propulsive efficiencies of 7 to 9 percent are possible. Contra-rotating propeller systems were applied to all generic U.S. flag liner vessels having installed horsepower levels greater than 20,000 SHP. A more detailed discussion of this program area is contained in Appendix B.

(9) Propellers In Nozzles (KORT)

Locating a propeller within a nozzle is an effective way to increase the effective thrust of a highly loaded propeller. Increases in the propulsive efficiency of low speed full hull forms of 6 to 15 percent have been demonstrated. Propellers in nozzles were applied to the generic U.S. flag 150,000 DWT tanker. A more detailed discussion of this program area is contained in Appendix B.

(10) Submerged Air Cushions (SAC)

Submerged air cushions replace the hull/water interface on the bottom of a vessel's hull with an air/water interface. This effectively eliminates the frictional resistance associated with that portion of the hull. Reduction in required horsepower levels for full slow hull forms are on the order of 16 to 20 percent. Submerged air cushions were applied to the generic U.S. flag 150,000 DWT tanker. A more detailed discussion of this program area is contained in Appendix C.

(11) Cutaway Hulls (CH)

The cutaway hull decreases the displacement of a tanker's hull below the ballast waterline. The expected gains are either an increase in speed in the ballast condition or a decrease in required horsepower to maintain the same speed. The cutaway hull was applied to the generic U.S. flag 150,000 DWT tanker. A more detailed discussion of this program is contained in Appendix C.

(12) Tunnel Sterns (TS)

Tunnel sterns are used to entrain water and lift it up and over the top of a large slow turning propeller. Net propulsive efficiency improvements on the order of 5 percent have been estimated for full slow hull forms. Tunnel sterns were applied to all generic U.S. flag bulk carriers. A more detailed discussion of this program area is contained in Appendix C.

(13) Hull Maintenance and Smoothing (HMS)

Inhibiting the degradation in propulsive efficiency that occurs with fouling and corrosion offers an energy conservation potential on the order of 6 percent for ocean going vessels. Hull maintenance and smoothing programs were applied to all generic U.S. flag ocean going vessels. A more detailed discussion of this program area is contained in Appendix C.

(14) Vessel Routing (VR)

Weather routing of vessels to minimize operational disruptions of those ocean going vessels that are tied to schedules offers a modest energy use and cost reduction potential. A more detailed discussion of this program area is contained in Appendix D.

(15) Vessel Operations (VO)

A maintenance and propulsion plant performance monitoring program can reduce fuel consumption by operating a main propulsion plant at its design conditions and minimizing auxiliary loads. Fuel savings on the order of 5 percent have been demonstrated. Vessel operation programs were applied to all generic U.S. flag steam powered vessels. A more detailed discussion of this program area is contained in Appendix D.

2. STEP 2 — DETERMINATION OF ECONOMIC IMPACTS

In Task 1, operating and cost parameters were developed for each generic vessel type. These baseline parameters are given in Appendix F. Cost impacts associated with the implementation of each program area fell into two categories:

- Changes to acquisition costs
- Changes to daily operating costs
  - Wages
  - Stores and subsistance
  - Maintenance and repair
  - Insurance.

The changes in acquisition and operating costs were estimates based on information obtained from:

- Interviews with individuals concerned with either research or production in each of the program areas
- Published data from the Maritime Administration.

Specific changes to particular cost categories for each program area are contained in the appendices. The calculation of the economic impacts associated with these cost changes was accomplished by changing the baseline cost parameters of the MTEM.

3. STEP 3 — QUANTIFY ENERGY IMPACTS

Energy impacts were calculated using the MTEM. Parameters affecting the:

- Required horsepower
- Specific fuel consumption
- Fuel type

were modified to reflect changes occurring as a result of implementation of each program. Specific changes reflecting each program area are given in the appendices.

4. STEP 4 — CATEGORIZATION OF TECHNOLOGICAL RISK

The degree of technological risk associated with each program was determined based on a subjective analysis that included:

- The degree to which commercialization already exists
- The risk categorization estimated by individuals involved in current research and development programs.

Each program was assigned one of the following risk factors: low, medium or high. A low risk category assignment was made when some degree of commercialization currently exists. A medium risk category assignment was made when the current state-of-the-art was judged to have advanced to that point where the next most logical step is the development of prototype components followed by an installation and demonstration project. A high risk category assignment was made when the current state-of-the-art was judged to be in the developmental engineering state, or where prototype equipment is currently being developed for land based installation and consideration of a marine application should wait until initial development work and land based demonstration projects are completed.

5. STEP 5 — ESTIMATE COSTS OF ERDA FUNDED PROGRAMS

Estimates of funding requirements, durations, and earliest possible start dates for each of the 15 program areas were made. Where possible, the funding and time estimates reflect the considered judgments of individuals who are actively working in the program areas.

For those program areas classed as high technological risk items, the level of funding and time durations are those that would bring the technologies involved to a point where a decision could be made as to the feasibility of continuing to the demonstration project stage. For those program areas classed as medium technological risk items, the estimates reflect what is necessary to fund demonstration projects. Low risk programs are already at the commercialized stage and little technological work or advancement was considered to be required.

The results of the analysis and the conclusions and recommendations are presented in the following chapter.

III. RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

III. RESULTS, CONCLUSIONS, AND RECOMMENDATIONS

The results of the analysis described in Chapter II are presented in Table III-1. Two general conclusions can be drawn from these results.

Table III-1
Results of Economic and Energy
Impact Analysis

Level of Technological Risk	Program Area	Range of Reduction in Required Freight Rate (%)		Energy Conservation Potential (% of U.S. Flag Consumption)	Potential Program Start	Program Duration (Years)	Estimated Funding Requirements (Millions of $)
		Minimum	Maximum				
Low	SSD	1.7	8.6	5.5	FY-78	2	0.500
Low	VO	0.3	2.1	1.4	FY-78	-	NONE
Low	VR	0.0	0.0	0.0	FY-78	-	NONE
Medium	DBC	6.7	10.2	3.6	FY-78	2	3.000
Medium	HMS	0.4	5.5	3.1	FY-78	1	0.250
Medium	GTCC	0.8	9.7	1.2	FY-78	2-3	4.000
Medium	TS	0.2	2.3	0.6	FY-78	1	0.300
Medium	CR	1.8	3.4	0.5	FY-78	2-3	4.000
Medium	HPTRS	4.5	9.3	0.4	FY-78	10	3.000
Medium	KORT	0.9	0.9	0.0	FY-78	2-3	1.000
Medium	CH	0.1	0.1	0.0	FY-78	1	0.300
High	AD	7.5	18.3	10.2	FY-80	5	2.000
High	NAHBE	5.6	6.7	5.4	FY-79	3	1.000
High	CCGT	6.4	11.4	1.4	FY-80	6-7	50.000
High	SAC	1.9	1.9	0.0	FY-78	1	0.400

ALL PROGRAM AREAS IDENTIFIED SHOW A NET ECONOMIC BENEFIT

As shown in columns three and four of Table III-1, the introduction of each of the program areas into the current U.S. flag fleet resulted in a reduction of the required freight rate (RFR) for all applications.

The percentage reduction varied due to applications on different vessels and trade routes. The assumption upon which the economic analysis were based are considered conservative:

- Residual and diesel fuel priced at $13.02/bbl
- 20-year lifetime
- Straight line depreciation
- 5 percent escalation in fuel costs per year.

Of the 15 program areas considered, three programs:

- Diesel bottoming cycles
- Adiabatic diesels
- Closed cycle gas turbines

showed the greatest percentage reduction in RFR.

2. <u>TWELVE OF THE FIFTEEN PROGRAM AREAS HAVE ENERGY REDUCTION POTENTIALS BETWEEN 0-5 PERCENT AND THREE HAD REDUCTION POTENTIALS BETWEEN 5-10 PERCENT</u>

Column V of Table III-1 presented the results of the energy impact analyses. Three program areas had an energy reduction potential greater than 5 percent:

- Slow speed diesels (SSA)
- Adiabatic diesels (AD)
- Naval Academy heat balance engine (NAHBE)

The energy conservation potential of each program area was calculated by introducing the specific technology represented by each program area in the current U.S. flag fleet and simulating the operation of this fleet in the 1974 base year cargo movements. The energy conservation potential was the difference between the energy required to transport the base year cargo movements with the existing fleet and that required to transport the same cargo movements with the modified fleet.

3. <u>THREE PROGRAM AREAS ARE RECOMMENDED FOR FUNDING IN FY78.</u>

Three program areas are recommended for funding in FY78. Based on the energy savings potential identified in Table III-1, the program areas in:

- Slow speed diesels (SSD)
- Diesel bottoming cycles (DBC)
- Hull maintenance and smoothing (HMS)

offer the greatest potential for future energy savings. All three programs are complementary and potential applications exist in all seven industry sectors, as shown in Table III-2.

Table III-2
Applications of Recommended Program Areas

Program Areas	Industry Sector						
	Foreign Trade	Great Lakes	Inland Rivers	Coastal	Offshore	Pleasure	Fishing & Misc.
Slow Speed Diesels	•	•		•			
Diesel Bottoming Cycles	•	•	•	•	•	•	•
Hull Maintenance and Smoothing	•	•	•	•	•		•

The elements of each of these program areas are discussed below.

(1) Recommended Program Elements in the Slow Speed Diesel Program Area

Two topics in the slow speed diesel program area require further investigation.

The first is an investigation into the interrelationship of fuel quality, engine reliability, maintenance programs and fuel additives. The second is an evaluation of the potential for and methods to prevent cold and corrosion in the exhaust waste heat recovery units due to operation of slow speed diesels on heavy residual fuels. Costs associated with studies of this type should not exceed $250,000 each.

(2) Recommended Program Elements in the Diesel Bottoming Cycle Program Area

Diesel bottoming cycles have advanced to the point where serious consideration should be given to funding a demonstration project. We recommended that a program to:

- Develop specifications and the design of a prototype exhaust heat recovery unit for installation on an inland river tow boat be started

- Construct, test and install the prototype

- Operate the system for a year as a demonstration project to prove the savings potential

be initiated. It is expected that this demonstration project would span approximately two years and cost approximately 2.5 to 3 million dollars.

(3) Recommended Program Elements in the Hull Maintenance and Smoothing Program Area

The Society of Naval Architects and Marine Engineers has recommended that additional research be undertaken to:

- Develop standard measurement techniques and equipment to describe hull surface profiles. These should be able to be used underwater

- Correlate in-service speed losses with surface roughness, time and operating and drydock costs

- Develop advanced hull and propeller maintenance procedures to reduce drag more effectively than currently available surface preparation, maintenance and cleaning methods

Based on the recommendations of the Society of Naval Architects and Marine Engineers, an initial assessment of current maintenance procedures, their costs and effectiveness is needed prior to funding additional work in this area. A study to:

- Correlate in-service speed losses, increased fuel consumption, lost time and operating, drydock and cleaning costs

- Identify and evaluate currently available hull maintenance programs and equipment

- Identify, evaluate and develop recommendations for areas of further work

is estimated at $250,000 with one year's duration.

4. THREE HIGH RISK PROGRAM AREAS SHOULD BE RECONSIDERED IN THE FUTURE

Basic research is currently being conducted in three program areas that offer a potential for significant energy savings should projected potentials be realized. These program areas are:

- Adiabatic diesel (AD)
- Naval Academy heat balance engine (NAHBE)
- Closed cycle gas turbines (CCGT).

Each of these program areas is presently being supported either by ERDA, the U.S. Navy, or the U.S. Army. Specific dates for the reevaluation of each of these program areas have been recommended and shown in Table III-1.

5. FOUR PROGRAM AREAS ARE RECOMMENDED FOR ACTION IN FY78 IN ANTICIPATION OF CARGO PREFERENCE LEGISLATION

Passage of cargo preference legislation by the U.S. Congress which would reserve up to 30 percent of all oil imports for U.S. flag tankers is expected over the next few years. Four program areas:

- Tunnel sterns (TS)
- Propellers in nozzles (KORT)
- Cutaway hulls (CH)
- Submerged air cushions (SAC)

were identified that specifically address tanker hull forms. The calculated energy conservation potential of these programs is low and was based on current trading patterns that have very little U.S. flag vessel participation. However, the energy consumed in 1974, in providing transportation for petroleum imports amounted to approximately 11 percent of the total maritime energy consumption. The evaluation of the four program areas presented in this report reflects the low participation by U.S. flag operators in this trade. The results would be entirely different if evaluated under an oil cargo preference scenario. In view of the likelihood for U.S. flag tanker preference legislation, it is recommended that preliminary programs in these four areas be started in FY-78.

APPENDIX A

MAIN PROPULSION PLANTS

APPENDIX A

MAIN PROPULSION PLANTS

Main propulsion plants used by the U.S. flag commercial transportation sector are of three general types:

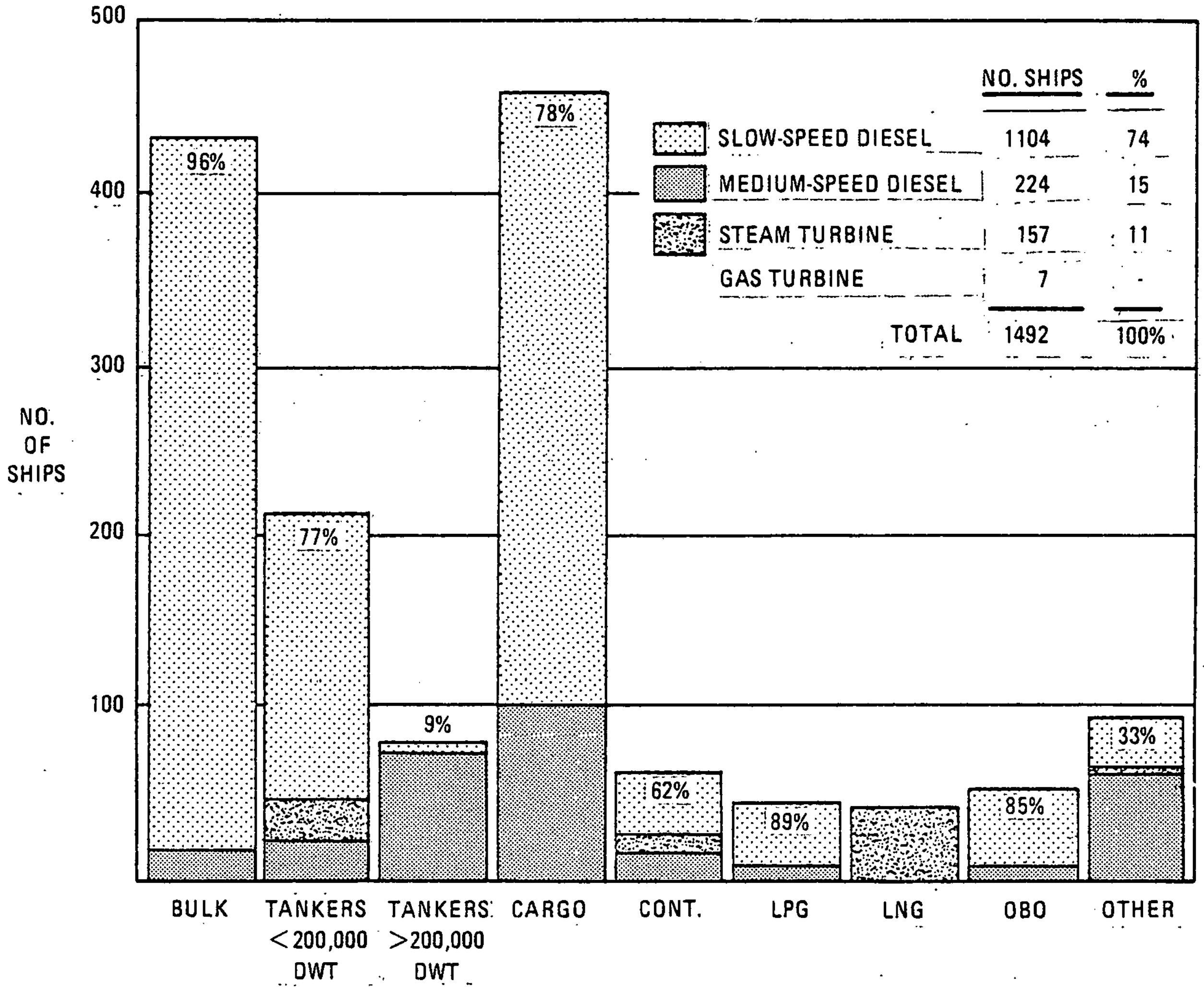
- Steam turbine, two heater 850 psig/950°F, used in ocean going vessels
- Diesel - medium speed or high speed, all other vessel types
- Industrial type gas turbines have been installed in a series of six-30,000 DWT tankers currently under construction.

The U.S. ocean going merchant fleet has traditionally been steam powered, while the remainder of the world's merchant fleet has been shifting more and more towards medium and slow speed diesel propulsion. Today, three types of main propulsion plants are being installed in any quantity worldwide. These plants and their applications are shown in Table A-1 and Figure A-1.

Table A-1
Main Propulsion Plant Applications

TYPE	HP RANGE	FUEL RATE #SHP-HR	FUEL TYPE
GEARED STEAM TURBINE	10,000 – 120,000	.40 – .47	RESIDUAL
GEARED DIESEL	9,500 – 20,000	.35 – .37	DIESEL
DIRECT DIESEL	7,000 – 40,000	.34 – .36	RESIDUAL

Gas turbines and combined steam and gas turbine cycles are being increasingly used in naval vessels. Their advantage being light weight and low maintenance. Naval applications have generally been marinized versions of aircraft



Source: "Motor Ship," December 1977.

FIGURE A-1
Summary of World Ships on Order - December 1976
(10,000 DWT and above)

derivative gas turbine. These units have also been utilized in a few high-speed merchant vessels. However, the most promising merchant applications of gas turbines have been based on the heavy duty industrial type, burning residual fuel. Six-10,000 SHP product tankers now under construction, are the only current U.S. commercial application of this type of power plant.

Geared steam turbines are being used almost exclusively in VLCC's and ULCC's outside the United States. Only in the

United States are medium-size tankers, bulk carriers and cargo vessels being built with steam plants. Until recently, the United States did not have the facilities to build large slow-speed diesels. However, this has changed with the signing of a licensing agreement between Westinghouse and Sulzer Brothers, Ltd., of Switzerland. Westinghouse is currently modifying fabrication facilities in California to build slow-speed diesels.

Seven program areas dealing with main propulsion plant research and development have been identified:

- High pressure/temperature reheat steam plants (HPTRS)
- Slow speed diesels (SSD)
- Diesel bottoming cycles (DBC)
- Adiabatic diesels (AD)
- Naval Academy heat balance engine (NAHBE)
- Heavy duty gas turbines and combined cycles (GTCC)
- Closed cycle gas turbines (CCGT).

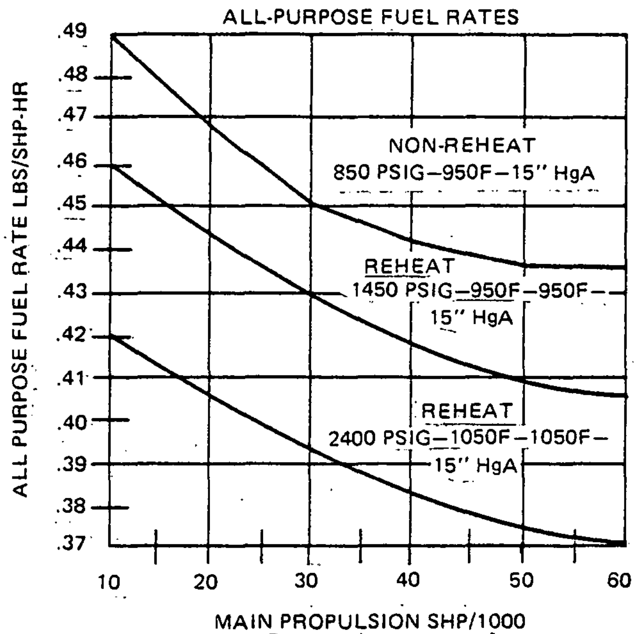
Each of these program areas is discussed below.

1. HIGH PRESSURE/TEMPERATURE REHEAT STEAM PLANTS

The General Electric Medium-Speed Turbine Division, supported by the U.S. Maritime Administration, has undertaken a design study of a high-performance marine reheat steam propulsion plant. The turbine design work is essentially complete.

The primary objective of the design study was to develop a steam propulsion plant having an all-purpose fuel rate of .36 to .38 lb/SHP-Hr, while burning residual fuel. Figure A-2 compares this goal with current marine steam practice.

The reheat steam plant identified in this design exercise had operating parameters of 2400 psig and 1050° F with one stage of reheat to 1050° F and a condenser vacuum of 1.5-inch HgA. The flow diagram for this plant is shown in Figure A-3.



Source: General Electric

FIGURE A-2
Typical Steam Plant Fuel Rates

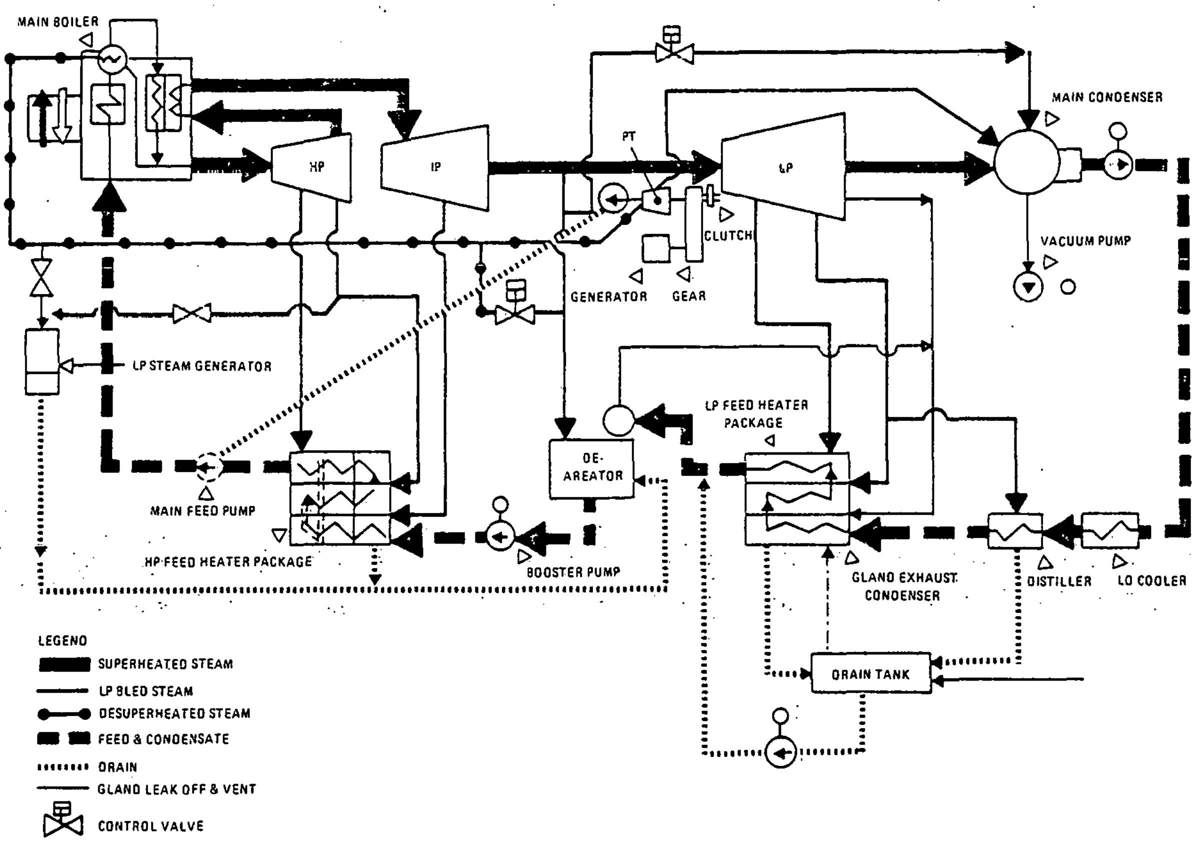
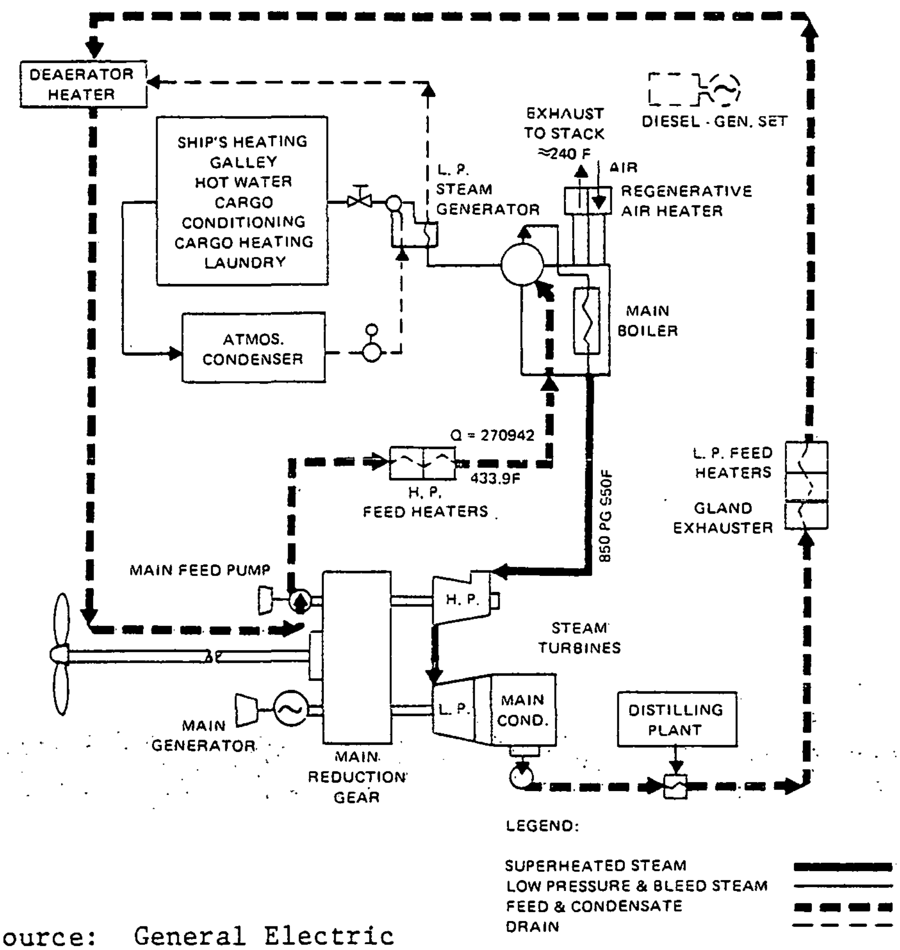


FIGURE A-3
Flow Diagram for G.E. 2400 PSIG/1050^{o}F/1050^{o}F
Reheat Steam Plant

Three factors are inhibiting the commercialization and acceptance of reheat steam systems in the United States. They are:

- Inherent complexity
- High initial first cost
- Expected increases in maintenance expenses and operational difficulty.

The degree of increased system complexity can be shown by comparing the flow diagram of the reheat plant, shown in Figure A-3 with a standard two-heater 850 psig/950°F steam plant, shown in Figure A-4.



Source: General Electric

FIGURE A-4
Flow Diagram for a Standard Two Heater 850 PSIG/950°F Steam Plant

In addition to the increased complexity, operational difficulties are experienced due to the need to control reheat while maneuvering or operating astern. During these periods of low power operation, reheated steam is not required and some method must be provided to prevent overheating the reheat superheater tubes. This is currently done through the use of dampers in a two pass gas flow boiler.

The higher initial first costs of a reheat versus non-reheat steam systems are more than compensated for through reduced fuel consumption. The potential for overall fuel rates in the .36 to .38 lb/SHP-Hr also make the reheat plants competitive with slow speed diesels in high power applications, in particular those vessels requiring large amounts of auxiliary steam and operating at power levels above the 35,000 to 40,000 horsepower range.

(1) Applications

Reheat steam systems were applied to all generic U.S. flag vessels having installed horsepower levels greater than 30,000 SHP. Fuel consumption, acquisition costs, maintenance and repair and insurance costs were varied, as shown in Table A-2.

Table A-2
Changes to Baseline Operational and Cost Parameters for High Pressure/Temperature Reheat Steam Systems

		Specific Fuel Rate		Acquisition Cost (Millions of $)		Maintenance & Repair ($/Day)		Insurance ($/Day)	
Vessel Type	DWT	Base Line	HPTRS	Base Line	HPTRS	Base Line	HPTRS	Base Line	HPTRS
Barge Carrier	33,000	.47	.39	53.0	53.4	899	909	822	840
Barge Carrier	42,000	.47	.38	57.0	57.4	1,334	1,354	1,639	1,657

The new cost and operational parameters were based on information published by the General Electric Company.

(2) Program Elements

At the present time, the technical feasibility of the marine reheat plant has been proven. General Electric estimates that initial application of the 2400 psig/1050°F/1050°F reheat plant is ten years away. Engineering developmental work on:

- Turbine
- Boilers
- Feed pumps
- Feed water treatment
- Gears

still remain to be completed. Funding requirements for the engineering development work required prior to actual construction and installation are on the order of $3 million.

2. SLOW SPEED DIESELS

As shown in Figure A-1, slow-speed diesels dominate the ocean shipping market. The primary advantage of slow-speed diesels is their low brake specific fuel consumption of .35 to .37 lb/BHP-Hr, depending upon type of engine, fuel burned and attached auxiliary equipment. The lack of domestic manufacturing capability has effectively blocked the use of slow speed diesels in U.S. merchant vessels. Almost all large merchant vessels constructed in the U.S. rely on some form of government aid in the form of construction and operational subsidies (CDS and ODS) or guaranteed mortgage financing (Title XI, mortgage insurance). The Merchant Marine Act of 1936, which provided these incentives, required the use of domestic equipment.

Westinghouse has requested and received from the U.S. Maritime Administration, waivers for certain slow speed diesel components which are currently not available domestically, such as turbochargers and crankshafts. Domestic manufacturing capability for these items must be developed, as the primary condition under which the waivers were granted was the requirement that subsequent units have a decreasing foreign component content.

Operational factors affecting the adoption of slow speed diesels by U.S. flag operators are:

- Reduced reliability vis-à-vis steam
- Requirement for fuel washing, filtering and centrifuging when burning heavy residual fuels
- High engine noise levels
- Increased weight vis-à-vis steam
- Higher overall maintenance cost when compared to steam
- Requirement to design the propeller to operate at an RPM higher than normal.

Positive factors other than the reduced fuel rates that may influence the U.S. operators' decision to use slow speed diesels in lieu of steam are:

- Reduced acquisition costs up to 30,000 BHP for the slow speed diesel vis-à-vis conventional steam plants and 40,000 BHP for reheat steam plants
- An established worldwide parts and service network
- An effective "take-home" capability that allows the vessel to operate on a reduced number of cylinders and/or without the turbocharger.

(1) Applications

Slow speed diesels were applied to generic U.S. flag vessels having installed horsepower levels greater than 12,000 SHP, which is the lowest power level that Westinghouse expects to produce. Two generic vessel classes were excluded from application considerations. Roll-on/Roll-off and barge carrying ships have cargo stowage and access requirements that effectively eliminate slow speed diesels from consideration due to their high headroom requirements. In the evaluation of slow speed diesels, fuel consumption, acquisition costs, maintenance and repair and insurance costs were varied, as shown in Table A-3.

Table A-3
Changes to Baseline Operational and Cost Parameters for Slow Speed Diesels

Vessel Type	DWT	Specific Fuel Rate		Acquisition Costs (Millions of $)		Maintenance and Repair ($/Day)		Insurance ($/Day)	
		Baseline	SSD	Baseline	SSD	Baseline	SSD	Baseline	SSD
Container	16,500	.47	.37	32.2	31.6	750	850	1,022	1,000
Container	18,500	.47	.37	43.1	42.5	827	937	1,022	1,000
Container	23,000	.47	.37	47.4	47.3	1,028	1,218	1,781	1,777
Breakbulk	13,500	.47	.37	30.0	29.3	746	829	1,025	995
Tanker	65,000	.47	.37	27.0	26.3	994	1,071	940	912
Tanker	80,000	.47	.37	31.0	30.4	1,160	1,254	1,211	1,187
Tanker	150,000	.47	.37	68.6	68.1	1,333	1,458	1,608	1,590
Coastal Tanker	40,000	.47	.37	20.2	19.4	899	959	822	790

These new cost and operational parameters were based on a recent paper that compared the economic performance of various marine power plants. This study was funded by the Maritime Administration.

(2) Program Elements

Two areas require further investigation in the slow speed diesel area. First is an investigation into the interrelationship of fuel quality, engine reliability, maintenance programs and fuel additives. Secondly is an evaluation of the potential for and prevention of cold end corrosion in the waste heat boiler (bottoming cycle) due to operation on heavy residual fuels. Costs associated with studies of this type should not exceed $250,000 each.

3. DIESEL BOTTOMING CYCLES

Concurrent with this contract effort, Booz, Allen is conducting an analysis of the application of exhaust heat recovery systems to marine diesel engines, for the Energy Research and Development Administration. Preliminary results of that analysis indicate that the potential for fuel conservation through recovery of heat contained in exhaust gases on a 1,350 horsepower inland river towboat are on the order of 15 to 18 percent.

(1) Applications

Diesel bottoming cycles were applied to all generic U.S. flag vessels that currently use medium speed diesel engines for their main propulsion plant. In the evaluation of diesel bottoming cycles, fuel consumption acquisition costs and maintenance and repair costs were varied, as shown in Table A-4.

Table A-4
Changes to Operational and Cost Parameters for Diesel Bottoming Cycles

Vessel Type	DWT	Specific Fuel Consumption		Acquisition Costs (Millions of $)		Maintenance and Repair Costs ($/Day)	
		Baseline	DBC	Baseline	DBC	Baseline	DBC
Great Lakes Dry Bulk	4,180	.37	.31	13.90	14.2	649	665
Great Lakes Tanker	2,676	.37	.31	1.60	1.7	110	113
Great Lakes Tug	–	.37	.31	0.56	0.70	33	36
Coastal Tug	–	.37	.31	1.00	1.20	51	55
Inland River Tow Boat	–	.37	.31	.84	1.0	42	45

Changes in the operational and cost parameters were estimated, based on preliminary data developed during the concurrent study mentioned above.

(2) Program Elements

The level of technological risk associated with diesel bottoming cycles is low enough to seriously consider funding a demonstration project. The industry segment with the largest population and accounting for the greatest consumption of diesel fuel is the inland waterway sector. A program to:

- Develop specifications and design of a prototype exhaust heat recovery unit
- Fund construction and installation of the prototype on an inland river towboat
- Operate the system for a year as a demonstration project to prove the savings potential to the inland river towing industry

would span approximately two years and cost approximately $2.5 to $3 million.

4. ADIABATIC DIESELS

Cummings Diesel, in partnership with the U.S. Army Tank Command, is conducting research into the adiabatic diesel. The goal of this program is the development of an engine with true adiabatic compression of the fuel air mixture in a diesel cycle without loss or gain of heat. The approach taken by Cummings Diesel is to insulate the combustion chamber, remove the cooling system and operate at high cylinder temperatures (approximately 1,500°F, instead of a normal 1,150°F exhaust temperature).

The goal of the U.S. Army is to develop a smaller, lighter, more efficient main battle tank engine. The scope of the Army's participation in this research program covers two phases:

- Phase I — $800,000 over the next three years with Cummings matching these funds. The goal is to produce a multiple cylinder engine capable of producing 500 hp maximum continuous rating (MCR) (700 HP peak) at 2100 RPM for 250 hours with a brake specific fuel consumption of .28 lb/BHP-Hr. This engine will be turbocharged and turbocompounded.
- Phase II — $10 to $12 million (FY77 dollars) to produce ten engines for extensive field tests.

Cummings is currently working with a single cylinder engine equipped with a ceramic piston cap. They have run this engine for 80 hours. The tests were stopped due to a failure of the wrist pin.

Reliability and operating criteria for a military diesel and a commercial marine diesel are extremely different. The goal of current programs is the development of an engine that will produce more horsepower from a smaller, lighter engine having an expected life of 500 to 1,000 operating hours at variable power levels. Table A-5 compares military and commercial maritime applications.

Table A-5
Medium-Speed Commercial Marine and Adiabatic Military Diesels

TYPE	HORSEPOWER RANGE	RPM	EXPECTED LIFE	FUEL	OPERATING PROFILE
ADIABATIC MILITARY	500 – 700	2100	500 – 1000 HR	DIESEL	WIDE POWER LEVELS BIASED TOWARDS IDLE
COMMERCIAL MARINE	500 – 10,000	300 – 450	20,000 – 24,000 HR	DIESEL	NARROW POWER OPERATING RANGE BIASED TOWARDS MCR

The Army and Cummings expect to eventually use composit ceramic cylinder liners, ceramic piston caps and ceramic headliners in the first production engines. Problems encountered include:

- Producibility (at production line rates) of the ceramic components
- Current lube oil consumption is ten times normal
- Lube oil is breaking down at the high operating temperatures.

These developmental problems were expected and the degree of technical risk is estimated as medium.

Reliability and costs are the two factors considered by an operator in any marine equipment purchase. When the purchase decision concerns the main power plant, reliability considerations are paramount. The goal of 500 to 1,000 hours meantime between overhauls (MTBO) for the current program would seem to exclude the adiabatic diesel from any maritime application. However, engine life is a function of operating RPM. If a direct relationship is assumed between engine life and RPM, then the 500 to 1,000 hours MTBO at 2,100 RPM for the adiabatic diesel becomes 3,500 to 7,000 hours at 300 RPM. These MTBO times become attractive, as current MTBO times for medium speed marine diesels are on the order of 15,000 to 20,000 hours.

(1) Application

Adiabatic diesels were applied to all generic U.S. flag vessels that currently use medium speed diesel engines for their main propulsion plant. In the evaluation of adiabatic diesels, fuel consumption and stores and subsistance costs were varied, as shown in Table A-6.

Table A-6
Changes to Operational and Cost Parameters for Adiabatic Diesels

Vessel Type	DWT	Specific Fuel Consumption		Stores and Subsistance Costs ($/Day)	
		Baseline	AD	Baseline	AD
Great Lakes Dry Bulk	4,180	.37	.28	679	1,249
Great Lakes Tanker	2,676	.37	.28	90	290
Great Lakes Tug	–	.37	.28	33	153
Coastal Tug	–	.37	.28	80	360
Inland River Tow Boat	–	.37	.28	67	192

Production and maintenance and repair costs of the adiabatic diesel were estimated by Cummings to be equal to conventional diesels. The elimination of the cooling system and its associated repair problems were expected to offset the increased costs of ceramic components and maintenance problems associated with the higher operating temperatures. Stores and subsistance costs were increased to reflect the increased lube oil consumption expected for the adiabatic diesel.

(2) Program Elements

Given the expected benefits of the adiabatic diesel, the results of the current research effort should be reviewed next fiscal year with an expected participation directed towards development of a marine engine. Given the level of effort of the U.S. Army's program, costs are estimated at $2 million over a five-year period to develop a prototype engine.

5. NAVAL ACADEMY HEAT BALANCE ENGINE

The Naval Academy heat balance engine (NAHBE) is based on a nonadiabatic compression process that utilizes retained heat and shock waves to enhance the combustion efficiency. Improvements in thermal efficiency on the order of 45 percent over the OTTO cycle for some off peak operating regimes have been claimed. Figure A-5 displays the combustion process which entails the following sequence:

1. "Piston approaches top dead center, intake valve opens and intake stroke begins.

2. Initial portion of intake stroke air enters the cylinder through auxiliary inlet (D), followed by a fuel-air charge from venturi (E).

3. Charge is stratified with a very lean composition just above the piston.

4. Compression forces air into reservoir (B), also known as balancing chamber.

5. Ignition causes rapid pressure buildup with large pressure ratio occurring across gap (C). Subsequent shock compression wave propagates under piston cap with expansion wave propagating upward into combustion chamber.

6. Shock compression under cap builds pressure to higher value than above cap causing air to flow to combustion chamber (A)." *

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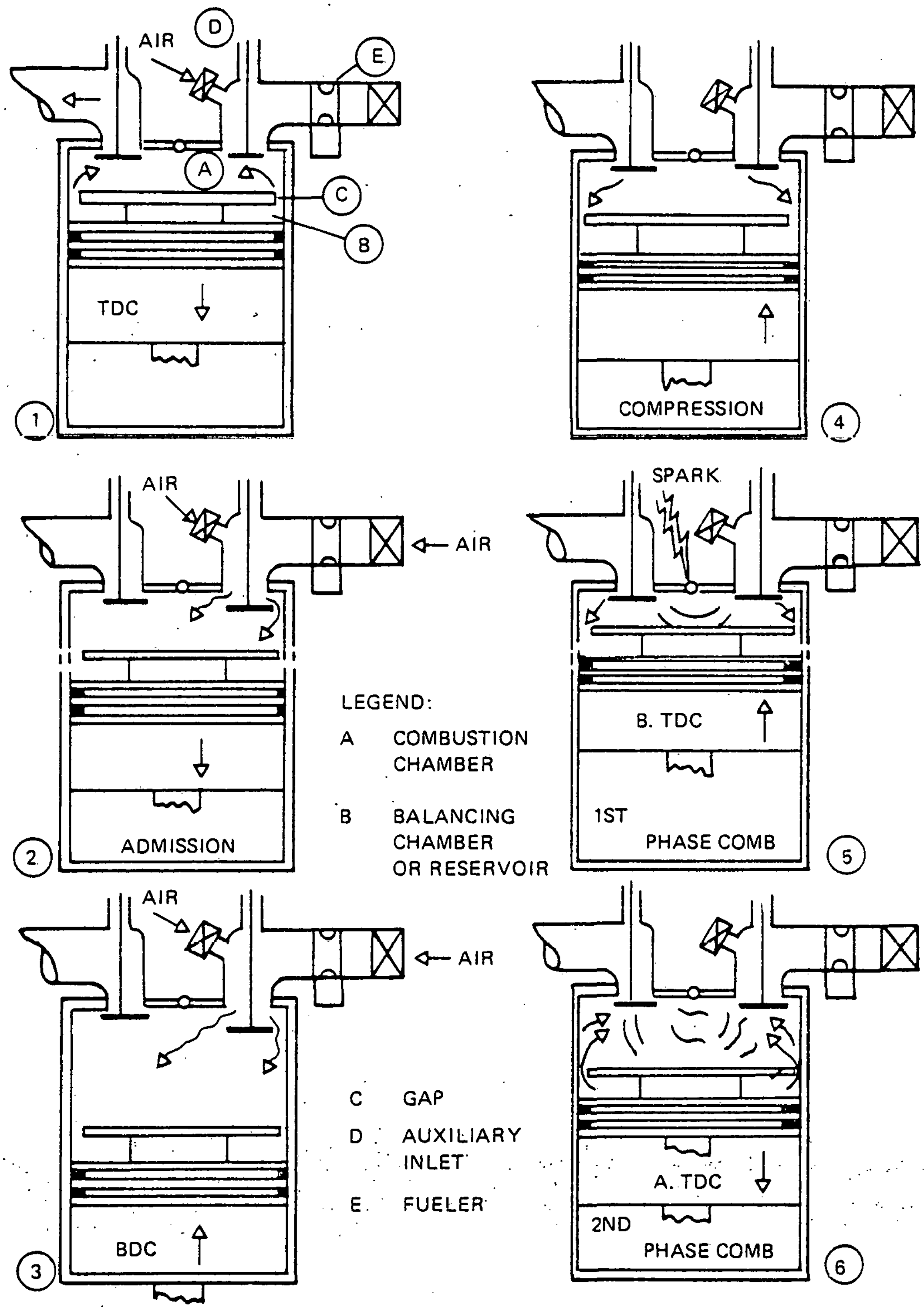
* "The Naval Academy Heat Balance Engine," Blaser, Pouring, Keating, and Rankin, June 1976, Naval Academy Report E.W. 8-76, p. 3-5.



Source: "Naval Academy Heat Balance Engine," Blaser, Pouring, Keating & Rankin, June 1976, Naval Academy Report E.W. 8-76, p. 4.

FIGURE A-5
Naval Academy Heat Balance Engine Cycle

Two nonadiabatic processes take place during this cycle:

- Heat input from the piston cap
- Heat input from the shock waves generated during the passage of the air into the balancing chamber.

Research into the Naval Academy heat balance engine is currently being funded by the Office of Naval Research (ONR), directed at defining the nonadiabatic process and quantifying the contribution of the shock waves and heat retention ability of the piston cap. This research effort is expected to be completed by the beginning of FY78. Assuming substantiation of the theory, ONR plans a two-year program to:

- Complete computer modeling of the combustion process and develop a new engine design
- Construct and test an engine based on the NAHBE theory.

Costs estimated for the complete program are on the order of $1 million.

(1) Application

The Naval Academy heat balance engine was applied to all generic U.S. flag vessels that currently use medium-speed diesels for their main propulsion plant and whose installed horsepower is less than 4,000 BHP. In the evaluation of the Naval Academy heat balance engine, fuel consumption was varied, as shown in Table A-7.

The minor nature of the modifications involved in incorporating the Naval Academy heat balance engine principle are well within the existing technology base. Based on this, the acquisition and operating costs of all applications were assumed to remain constant.

Table A-7
Changes to Operational and Cost Parameters for the Naval Academy Heat Balance Engine

Vessel Type	DWT	Specific Fuel Consumption	
		Baseline	NAHBE
Great Lakes Tanker	2,676	.37	.34
Great Lakes Tug	–	.37	.34
Coastal Tug	–	.37	.34
Inland River Tow Boat	–	.37	.34

(2) Program Elements

Research into the technological principles underlying the Naval Academy heat balance engine is currently being funded by the Office of Naval Research with preliminary results expected to be available by FY78. Given the expected level of effort, estimated by the Navy, costs of a ERDA funded program are estimated at $1 million over a three-year period to develop a prototype engine. Any action in this area should wait until the completion of the work currently being funded by the Office of Naval Research.

6. HEAVY DUTY GAS TURBINE COMBINED CYCLES

In recent years, heavy duty gas turbines for marine propulsion systems have been receiving more attention from commercial operators. The gas turbine offers the commercial marine operator the following advantages:

- Ease of starting
- Ease of automation
- Low specific weight and volume
- Low initial first cost
- High reliability.

From the operator's viewpoint, ease of starting and automation are reflected in reduced manning requirements.

The low specific weight and volume means more cargo carrying capability and the low initial first cost is reflected in reduced capital charges.

In 1970, the General Electric Company's Gas Turbine Products Division and the Maritime Administration, entered into a five-year research program to produce an advanced heavy duty regenerative gas turbine which would be economically competitive and technically acceptable to the U.S. Merchant Marine. Three factors had contributed to the unacceptability of the heavy duty gas turbine as a main propulsion plant:

- High specific fuel consumption
- Unproven capability to burn residual heavy fuel, without adverse maintenance effects
- Need for an external device for reversing the direction of propeller thrust.

The General Electric-MarAd program produced significant advances in the state-of-the-art. Specifically:

- Development of a more efficient regenerator design with weight, space and costs reduced on the order of 20 to 30 percent
- Designed, constructed and tested a reversing gas turbine with an approximate loss in efficiency of 5 percent when compared to the nonreversing gas turbine
- Proved the ability to burn treated residual fuels with no adverse maintenance effects.

To date, approximately 15 vessels worldwide have been fitted with heavy duty gas turbines, as shown in Table A-8.

Current applications of the heavy duty gas turbine have a specific fuel consumption range, as shown in Table A-9.

Table A-8
Commercial Heavy Duty Gas Turbine Installations

OPERATOR	SHIP DESCRIPTION	NO. OF SHIPS	TRANSMISSION	SHP
THE BROKEN HILL PROPRIETARY CO., LTD.	14,000 DWT STEEL PRODUCTS CARRIER	2	GEAR CRP	19,000
HILMAR REKSTEN	29,000 M^3 ETHYLENE METHANE CARRIER	1	GEAR CRP	20,000
STANDARD OIL CO. OF CALIFORNIA	35,000 DWT PETROLEUM PRODUCTS CARRIER	6	AC/AC CRP	10,000
UNION STEAMSHIP COMPANY OF NEW ZEALAND	5,500 DWT ROLL ON/ ROLL OFF CARRIER	2	AC/DC FPP(2)	10,000
UNION STEAMSHIP COMPANY OF NEW ZEALAND	12,200 DWT ROLL ON/ ROLL OFF CARRIER	2	AC/AC CRP(2)	25,200
THE BROKEN HILL PROPRIETARY CO.,	43,700 DWT BULK CARRIER	2	GEAR CRP	9,900

CRP - CONTROLLABLE REVERSIBLE PITCH PROPELLER.
FPP - FIXED PITCH PROPELLER.

Source: "Five Years' Experience in Applying Heavy Duty Gas Turbines to Marine Propulsion," Critelli & Rowen, SNAME Transactions 1975.

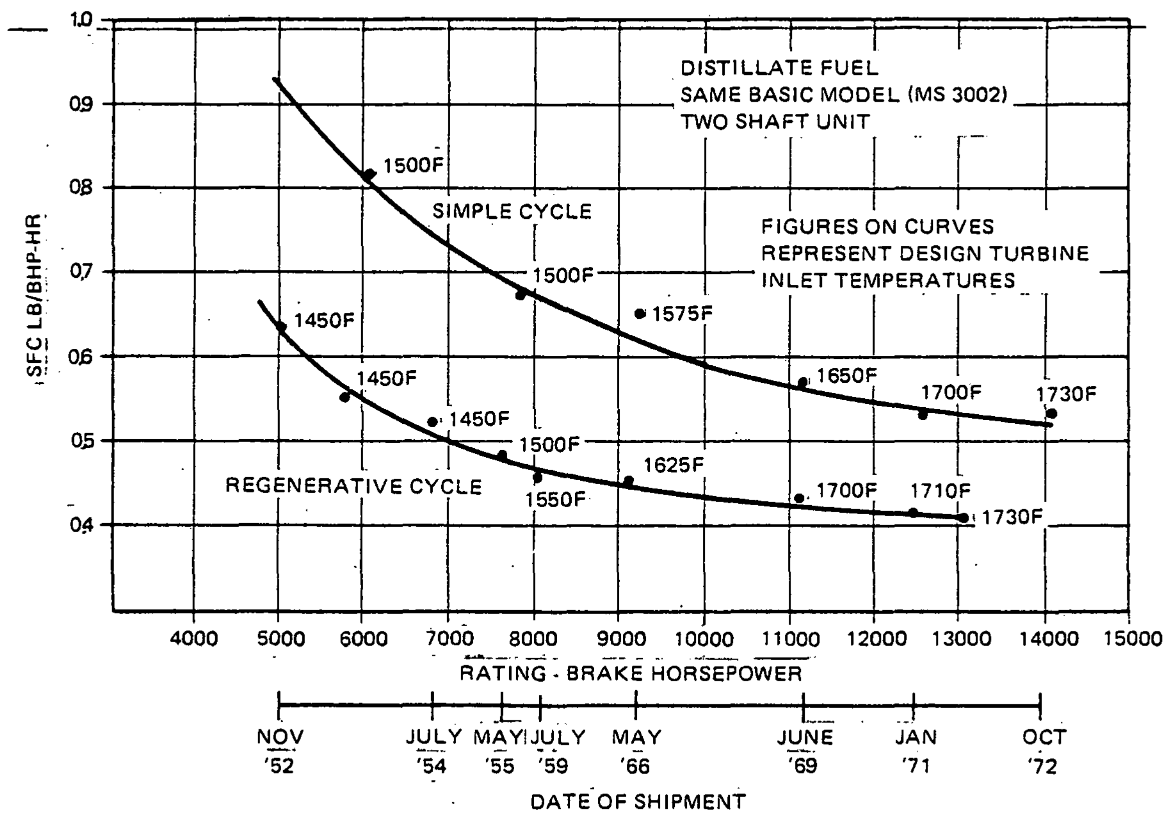
Table A-9
Specific Fuel Consumption Rates of Current Heavy Duty Marine Gas Turbines

	DISTILLATE		RESIDUAL	
PLANT TYPE	BREAK HORSEPOWER	SFC LB/BHP-HR	BREAK HORSEPOWER	SFC LB/BHP-HR
MS-3002	12,650	.420	11,550	.453
MS-5002R "A"	23,850	.417	22,300	.448
MS-5002R "B"	29,300	.418	27,450	.450
MS-7002R	59,800	.424	55,450	.466

Source: "Five Years' Experience in Applying Heavy Duty Gas Turbines to Marine Propulsion," Critelli & Rowen, SNAME Transactions 1975.

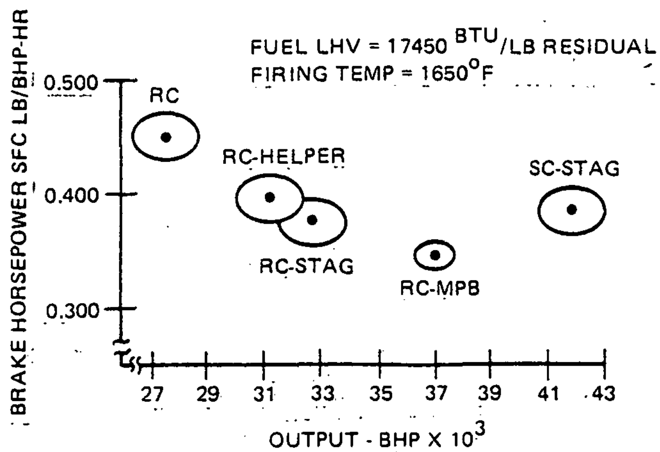
Improvements to the specific fuel consumption of the heavy duty gas turbine will come from two areas; uprating of the basic turbine through increased mass flow and higher firing temperatures and improved cycle efficiencies through the use of Rankin bottoming cycles.

The increase in cycle efficiencies gained by an increase in firing temperatures achieved over the past 15 years, is shown in Figure A-6 and the potential for improvement in cycle efficiency through the use of Rankin bottoming cycles is shown in Figure A-7.



Source: "Five Years' Experience in Applying Heavy Duty Gas Turbines to Marine Propulsion," Critelli & Rowen, SNAME Transactions 1975.

FIGURE A-6
Improvement in Specific Fuel Consumption of Heavy Duty Gas Turbines With Increasing Turbine Inlet Temperature



RC – REGENERATIVE CYCLE

SC – SIMPLE CYCLE

HELPER – RECOVERED POWER TO COMPRESSER

STAG – RECOVERED POWER TO PROPELLER SHAFT

MPB – MULTIPRESSURE WASTE HEAT BOILER

Source: "Five Years' Experience in Applying Heavy Duty Gas Turbines to Marine Propulsion," Critelli & Rowen, SNAME Transactions 1975.

FIGURE A-7
Effect on Specific Fuel Consumption of Heavy Duty Gas Turbines of Rankin Bottoming Cycles

The combined cycles shown in Figure A-7 are all based on a simple single pressure waste heat boiler. Additional improvements in specific fuel consumption have been shown to be achievable with a multiple pressure waste heat boiler. There is currently one land-based multiple pressure combined cycle plant which entered service in the 1960's. This plant rated at 50 megawatt, has achieved a net thermal efficiency of 42 percent or a specific fuel consumption of .345 lb/BHP-Hr. Fuel used in this installation is unknown.

(1) Application

The heavy duty gas turbine combined cycles were applied to all generic U.S. flag vessels whose installed horsepower was greater than 15,000 SHP, plus all Ro/Ro vessels irregardless of horsepower. In the evaluation of heavy duty gas turbine combined cycles, fuel consumption, acquisition costs, stores and subsistence, maintenance and repair and insurance costs were varied, as shown in Table A-10.

Table A-10
Changes to Operational and Cost Parameters for Heavy Duty Gas Turbine Combined Cycles

Vessel Type	DWT	Specific Fuel Consumption		Acquisition Costs (millions of $)		Stores and Subsistence ($/day)		Maintenance and Repair ($/day)		Insurance ($/day)	
		Baseline	GTCC	Baseline	GTCC	Baseline	GTCC	Baseline	GTCC	Baseline	GTCC
Container	16,500	.47	.43	32.2	33.7	100	180	750	807	1022	1052
Container	18,500	.47	.42	43.1	44.6	559	642	827	886	1022	1052
Container	23,000	.47	.41	47.4	49.1	495	621	1028	1110	1781	1815
Ro/Ro	16,500	.47	.42	38.0	39.6	449	551	1090	1160	1635	1667
Barge Carriers	33,000	.47	.39	53.0	54.4	424	566	899	987	822	850
Barge Carriers	42,000	.47	.37	57.0	59.1	751	922	1334	1431	1639	1681
Tanker	80,000	.47	.43	31.0	31.5	499	579	1160	1217	1211	1241
Tanker	150,000	.47	.42	68.6	70.1	551	643	1333	1398	1608	1639

The new cost and operational parameters were based on papers published by the Society of Naval Architects and Marine Engineers, and General Electric and interviews with individuals at the U.S. Maritime Administration.

(2) <u>Program Elements</u>

Programs in the gas turbine combined cycle area should address the two areas where the potentials for increased cycle efficiencies exist:

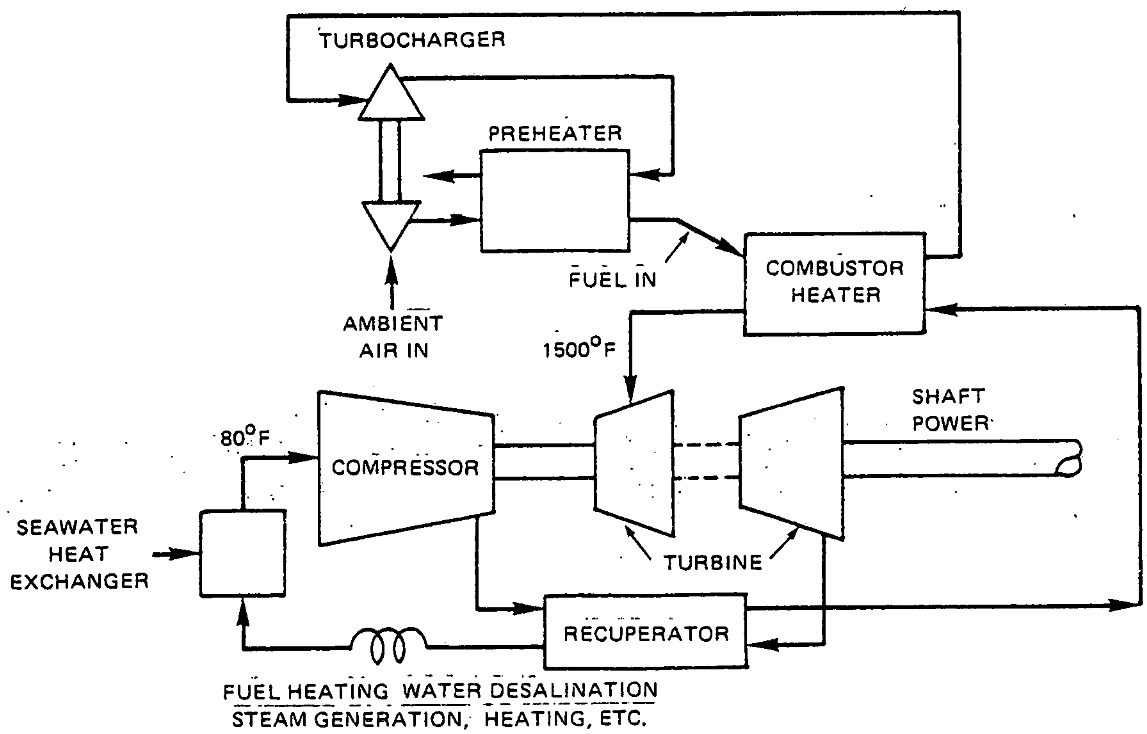
- Higher turbine inlet temperatures through use of ceramic materials being developed for the closed cycle gas turbine program
- Bottoming cycles either organic or steam and multiple pressure boilers.

Development of materials capable of withstanding higher turbine inlet temperatures is currently being pursued by a number of firms concerned with the development of open and closed cycle gas turbines. Applications of knowledge gained in this area will take place as new turbines are developed for industrial use.

Development of a prototype bottoming cycle and installation in a marine application has potential. Based on the program costs developed for the diesel bottoming cycles and discussions with the U.S. Maritime Administration, a program of the order of $4 million over three years is estimated for a heavy duty gas turbine combined cycle demonstration project.

7. CLOSED CYCLE GAS TURBINES

The closed cycle gas turbine differs from the open cycle in that the gases produced in the combustion process are not used in the power cycle. Instead, the combustion gases are used to heat a working fluid which is passed through the power turbine. An example of this cycle is shown in Figure A-8. One of the primary advantages of the closed Brayton cycle is its ability to burn coal and low grade residual fuels.



Source: Shipbuilding and Marine Engineering International, Sept. 1973.

FIGURE A-8
Closed Cycle Gas Turbine

Currently, research and development efforts are focused on the development of materials that will allow higher combustion and turbine inlet temperatures and as a result, greater fuel efficiencies. The AiResearch Corporation is currently engaged in closed cycle research, sponsored by:

- Energy Research and Development Administration
- Electric Power Research Institute
- U.S. Navy

designed to produce both metallic and ceramic materials that will be able to withstand temperatures on the order of 2200°F to 2300°F. The design work is keyed to a 300 to 350 megawatt land-based power station. Recent technical advances in the area of high temperature materials have led AiResearch to revise their ranking of the technological risk of developing materials for the 2200°F to 2300°F temperature range from high/medium to medium/low.

The current state-of-the-art will allow a closed cycle gas turbine for marine propulsion system to be built, with a temperature range on the order of 1,500°F and a cycle specific fuel combustion of .35 to .36 lb/SHP-Hr.

(1) Applications

Closed cycle gas turbines were applied to all vessels with installed horsepower levels over 20,000 SHP and all Ro/Ro vessels. In the evaluation of closed cycle gas turbines, fuel consumption and maintenance and repair costs were varied, as shown in Table A-11.

Table A-11
Changes to Operational and Cost Parameters
for Closed Cycle Gas Turbines

Vessel Type	DWT	Specific Fuel Consumption		Maintenance and Repair Costs ($/Day)	
		Baseline	CCGT	Baseline	CCGT
Container	23,000	.47	.36	444	488
RoRo	16,500	.47	.36	1,090	1,131
Barge Carrier	33,000	.47	.36	899	946
Barge Carrier	42,000	.47	.36	1,334	1,396

Cost estimates were based on information obtained in interviews with the U.S. Maritime Administration, AiResearch Corporation and published documents.

(2) Program Elements

Estimates supplied by AiResearch indicate that materials that will allow higher cycle efficiencies yielding a specific fuel consumption below .30 lb/SHP-Hr will be available within six to seven years. Costs to develop a 40,000 SHP marine power plant with a specific fuel consumption of .29 to .28 lb/SHP-Hr are estimated at $50 million, plus or minus 50 percent.

It appears that current technological advances have improved the closed cycle gas turbine systems to the point where their fuel economy is on the same order as that attainable with current commercially available slow speed diesels. Any further development work in the area of commercial marine transportation systems should wait until the current work on high temperature materials now being funded by ERDA, EPRI and the Navy is completed.

APPENDIX B

PROPULSORS

APPENDIX B

PROPULSORS

The selection and design of a propulsor is a complex trade-off analysis that considers:

- Power of the vessel
- Required service speed
- Operating draft
- Type of service
- Vibration characteristics and requirements
- Cavitation.

From the viewpoint of overall propulsive efficiency, the single screw vessel is preferable, as shown in Table B-1.

Table B-1
Propulsive Efficiency of Multiple Screw Vessels

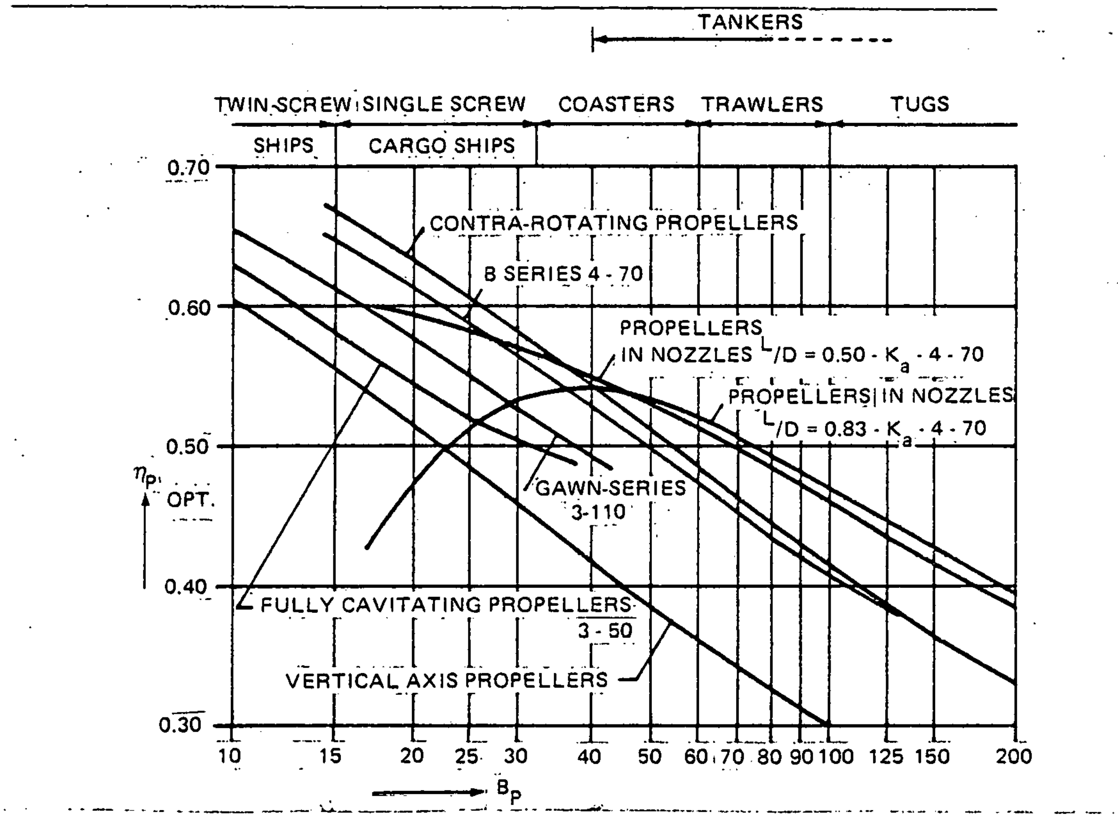
No. of Screws	Propulsive Efficiency (%)
1	70 - 80
2	60 - 70
4	55 - 65

Source: Marine Engineering, "Seward."

Commercial vessels, for the most part, rely on the single screw propeller, except in those unique instances where the propulsor choice is dictated by service or power requirements. Some examples of alternative propulsors are:

- Air screw — cross channel Hovercraft ferry
- Water jet — some ferry applications
- Multiple screw — merchant vessels in the higher horsepower ranges
- Vertical axis propellers — tugs with high maneuvering requirements.

In all cases, the choice of propulsor is limited by the application that the ship is being designed for. Figure B-1 shows the range of applications for different types of screw and vertical axis propellers.



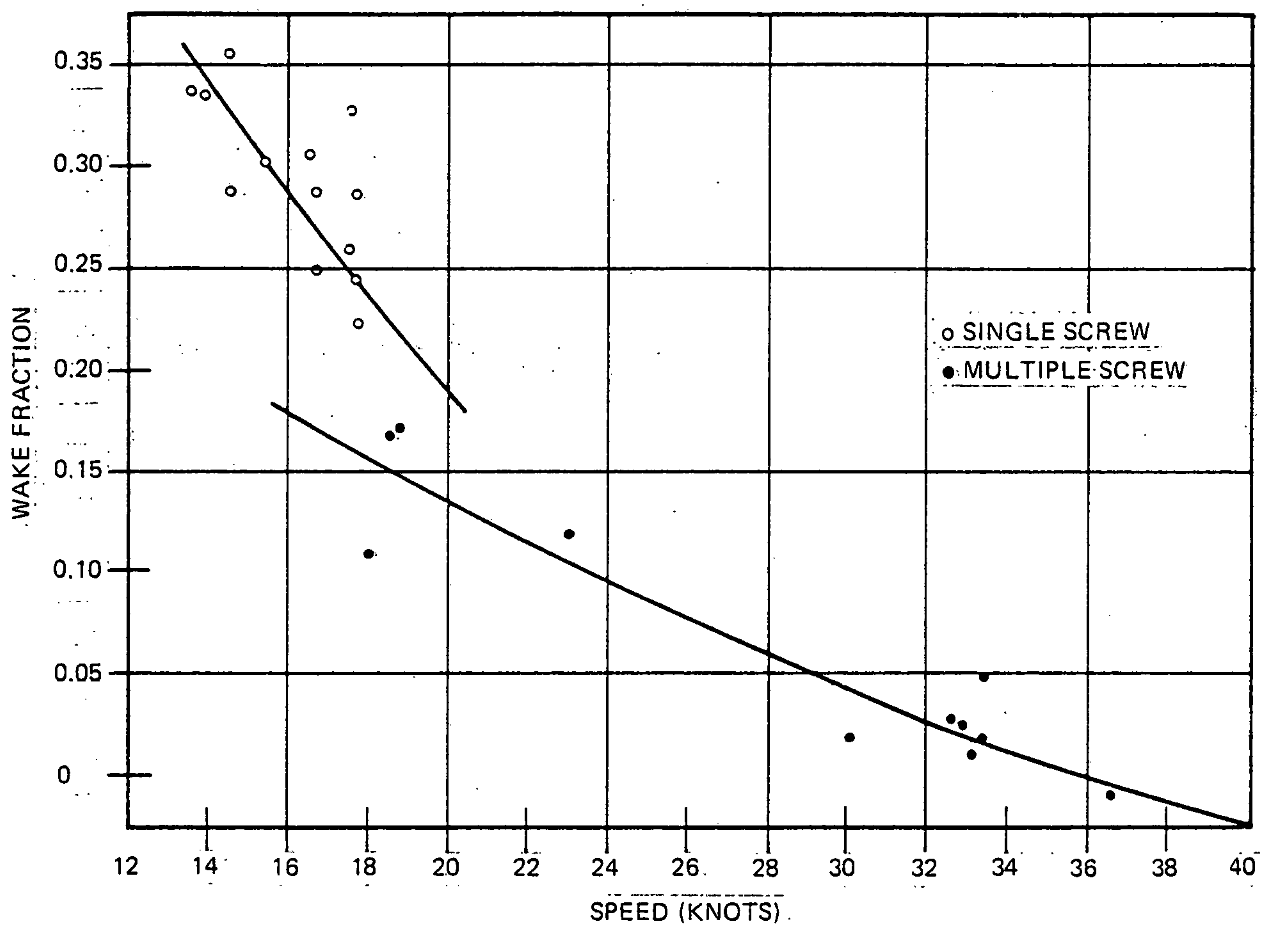
Source: "Marine Engineering," Seward, Society of Naval Architects and Marine Engineers

FIGURE B-1
Comparison of Optimum Efficiency Values for Different Types of Propulsors

In Figure B-1, the optimum efficiencies of various propeller types are plotted against the Taylor Power Coefficient, which is defined as:

$$B_p = \frac{N(P)^{0.5}}{(V_a)^{2.5}}$$

where N = propeller RPM
P = horsepower
V_a = speed of advance or $V(1-w)$
V = design speed of the ship
w = wake fraction as shown in Figure B-2.



Source: "Marine Engineering," Seward, Society of Naval Architects and Marine Engineers

FIGURE B-2
Wake Fraction Vs. Speed

For many ships, however, the design of the propeller does not correspond to that which would give the optimum propulsive coefficient for the specific type of hull form and power level, due to considerations of hull form, power and RPM of the prime mover, weight and space requirements of the reduction gears necessary to match main propulsion plant RPM to optimum propeller design, number of blades, vibration characteristics, draft, cavitation considerations, allowable propeller diameter, etc. These design constraints often reduce a single screws propulsive coefficient to a point where the advantages offered by going to a contra-rotating propeller system or a propeller in a nozzle are often more than the few percentage point difference shown in Figure B-1.

The propeller types shown in Figure B-1 all have their own applications. Currently, contra-rotating propellers are not utilized in merchant vessels. Fully cavitating and semisubmerged propellers are restricted to unique military and competition applications where speed is of paramount importance.

Two program areas in the propulsor category have been identified:

- Contra-rotating propellers (CR)
- Propellers in nozzles (KORT).

Each of the two areas is discussed in greater detail below.

1. CONTRA-ROTATING PROPELLERS

Contra-rotating propellers are a unique application where one propeller is located directly behind the other and rotates in the opposite direction. The advantages of the contra-rotating propeller are:

- The higher propulsive coefficients associated with single screw hull forms, as shown in Table B-1, are attainable

- Hull construction costs of single screw hull forms are cheaper than twin screw forms

- Lower fuel consumption due to the fact that one large engine is generally more efficient than two smaller engines.

Large bulk carriers and high speed liner vessels have reached horsepower levels that are at or beyond the point where they can be absorbed efficiently by a single screw. Containerships with sea speeds in excess of 23 knots and 30,000 SHP are at the point where cavitation and vibration problems start to become serious. Minor advances can and are being achieved through advanced propeller designs such as:

- High degree of skew and/or rake
- Large number of blades.

However, the advances to be made are minor when compared with other solutions.

Tests carried out at the Naval Ship Research and Development Center, Carderock, have indicated that a large U.S. built twin screw tanker of 43,000 SHP and a displacement of 136,000 long tons fitted with a contra-rotating propeller, could achieve a 7½ percent gain in SHP over the, as built, twin screw version and a 7 percent gain over the best results achieved with a single screw.

This potential for improvement associated with the contra-rotating propeller was confirmed by full-scale tests performed by the Navy. In actual installation test on a submarine, the Navy obtained improvements in the propulsive coefficient of approximately 7 percent over the single screw application. In addition, the Maritime Administration has conducted preliminary model tests on a Lykes Seebee class barge carrier and achieved an improvement in the propulsive coefficient on the order of 9 percent.

There are two factors that have effectively prohibited the installation of contra-rotating propellers:

- The transmission and shafting systems are extremely complex. Systems capable of absorbing power levels of 20,000 to 30,000 SHP are at the limits of the state-of-the-art.
- The first costs for a contra-rotating system are high.

(1) Applications

Contra-rotating propeller systems were applied to all generic U.S. flag liner vessels having an installed power level greater than 20,000 SHP. Horsepower levels, acquisition costs, maintenance and repair, and insurance costs were varied, as shown in Table B-2.

The changes in the operational and cost parameters were based on information gained in interviews with the U.S. Maritime Administration and the Naval Ship Research and Development Center.

Table B-2
Changes to Baseline Operational and Cost Parameters for Contra-Rotating Propeller Systems

Vessel Type	DWT	Horsepower		Acquisition Costs (Millions of $)		Maintenance and Repair Costs ($/Day)		Insurance Costs ($/Day)	
		Baseline	CR	Baseline	CR	Baseline	CR	Baseline	CR
Container	23,000	28,000	25,760	47.4	48.8	1,028	1,131	1,781	1,809
RO/RO	16,500	22,000	20,240	38.0	39.4	1,090	1,200	1,635	1,663
Barge Carriers	33,000	33,000	30,360	53.0	54.4	899	1,009	822	850
Barge Carriers	42,000	42,000	34,960	57.0	58.4	1,334	1,444	1,639	1,667

(2) Program Elements

The application of contra-rotating propellers to high powered merchant vessels is feasible. The Maritime Administration has developed, with the Curtiss-Wright Corporation, two prototype epicylic gear sets for 40,000 and 60,000 horsepower. The 60,000 HP set is equipped with contra-rotating output shafts. Engineering and developmental work remaining prior to a demonstration project must address:

- Stern seals
- Shafting
- Shaft bearings and lubrication.

Sun Shipbuilding Company of Pennsylvania is currently building a series of Ro/Ro vessels for the Totom Shipping Company. Totom has expressed an interest to the Maritime Administration in installing a prototype contra-rotating system on one of these vessels. The cost of a demonstration program has been estimated by MarAd to be on the order of $4 million, over a two to three year period.

2. PROPELLERS IN NOZZLES

Locating propellers within a nozzle is an accepted way to increase the effective thrust of a highly loaded propeller, as shown in Figure B-1. Use of kort nozzles is common practice on the inland rivers and to a lesser extent, on coastal tugs, and offshore supply craft.

Application of nozzles to large ocean going vessels with block coefficients of .85 and length-beam ratios of 5 or greater has recently been tried overseas, as shown in Table B-3.

Table B-3
Recent Large Commercial Ships Fitted
With Ducted Propellers

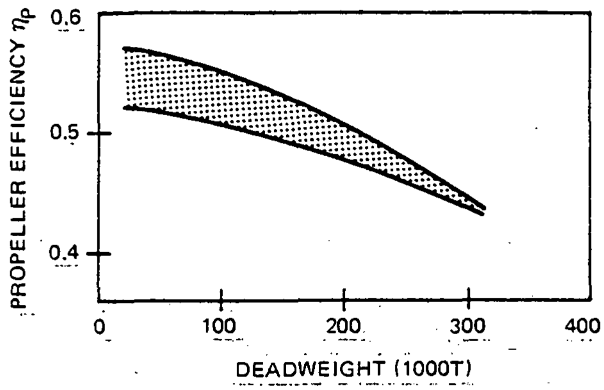
Vessel	Ship Type	Dead-Weight	Horse-Power	Delivery	Shipyard
Kronoland	Tanker	131,450	25,000	1970	Eriksberg
Golar Nichu and 3 Sister Ships	Tanker	215,780	30,000	1970-1972	Kawasaki
Thorsaga	Tanker	279,750	34,200	1973	Mitsui
Hoegh Hood	Ore/Oil Carrier	244,670	33,000	1973	Kawasaki

Source: "Application and Development of a Large Ducted Propeller for the 280,000 DWT Tanker MV THORSAGA," Narita, Kunitake and Yagi — Transactions, SNAME 1974.

Under the operating conditions associated with VLCC's, the propeller loading of these large vessels has become higher and the propeller efficiency has fallen off, as shown in Figure B-3.

The only known instance of the application of a nozzle to a large bulk carrier in the U.S. has been on a U.S. flag Great Lakes bulk carrier where increases in propulsive efficiency have ranged from 2 percent at partial loads to over 6 percent at full power.

Claims of fuel savings ranging from 6 to 15 percent have been made by Stone Manganese Marine and Strommen



Source: "Application and Development of a Large Ducted Propeller for the 280,000 DWT Tanker MV THORSAGA," Narita, Kunitake and Yagi — Transactions, SNAME 1974.

FIGURE B-3
Propeller Efficiency Vs. Deadweight

Staal, United Kingdom and Norwegian companies who design and produce ducted propellers for large vessels. The cost for installation of a ducted propeller has been estimated as approximately twice that of a conventional propeller.

An illustration of the potential for increased fuel economy is given in Figure B-4. This is a comparison of speed vs. shaft horsepower of 280,000 DWT tanker fitted with and without a nozzle. The curves represent actual trial data for a series of six 280,000 DWT tankers built by the Mitsui Shipbuilding and Engineering Company, Ltd. of Japan and show a 7 to 12 percent improvement over the design speed range at full load displacement. The curve representing the conventional propeller is an average of five identical tankers. The ducted power curve is taken from the sea trials of the MV THORSAGA, delivered in 1973.

(1) Application

Propellers in nozzels were applied to the generic 150,000 DWT U.S. flag tanker. Horsepower levels, acquisition and insurance costs were varied, as shown in Table B-4.

The changes in acquisition costs are based on data supplied through interviews held with individuals at the Naval Ship Research and Development Center.

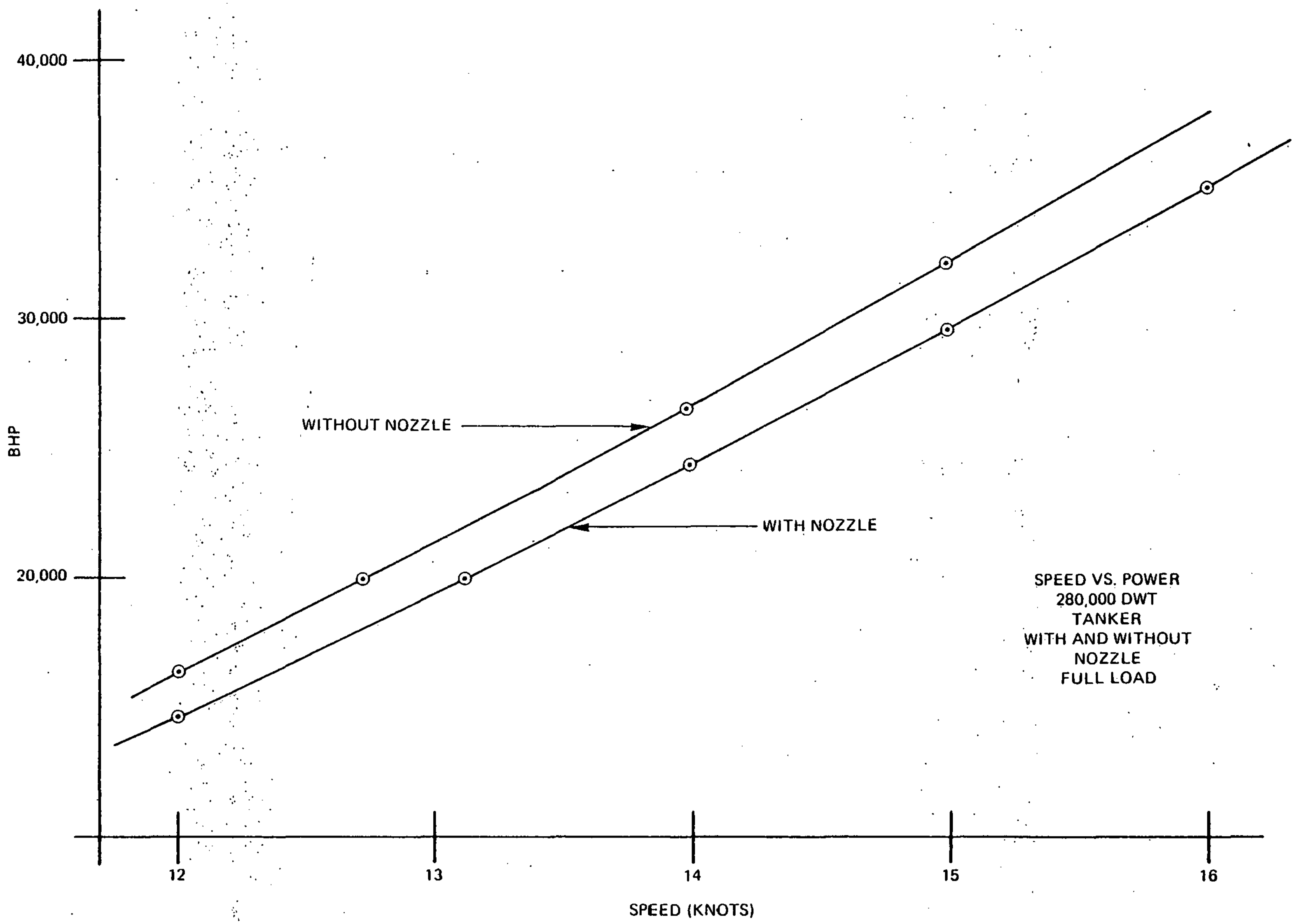


FIGURE B-4
Speed Vs. Power
280,000 DWT Tanker With and Without Nozzle Full Load

Table B-4
Changes to Baseline Operational and Cost Parameters for Propellers in Nozzels

Vessel Type	DWT	Horsepower		Acquisition Costs (Millions of $)		Insurance Costs ($/Day)	
		Baseline	KORT	Baseline	KORT	Baseline	KORT
Tanker	150,000	20,000	18,400	68.6	69.0	1,608	1,616

(2) <u>Program Elements</u>

Cavitation and vibration problems have been reported with all recent nozzle installations on large tankers. Recent technical papers published by the Japanese have indicated that cavitation problems can be eliminated through the use of air injected into the nozzle aft of the propeller plane. The vibration problems have been severe enough that all nozzles previously installed have been removed. It is suspected that lack of sufficient, structural reinforcement in the stern has caused the vibration problems. A demonstration project could be undertaken for approximately $1 million covering:

- Model test
- Redesign of the stern structure
- Construction and installation of the nozzle.

The program would span approximately two to three years.

APPENDIX C

HYDRODYNAMICS

Potential research and development programs in the generic technology area of hydrodynamics fall into two major subcategories:

- Hull performance
- Hull maintenance

In the area of merchant vessel hydrodynamic research, much of the effort directed towards hull performance, is focused on developing an understanding of the interactions that occur between the hull and propeller and developing hull forms for special applications. It is generally the response of the commercial maritime industry to outside or external forces in the form of mandated regulations that create an opportunity for significant increases in hull performance. In the area of hull maintenance, extremely significant reductions in energy use can be achieved.

1. THREE PROGRAM AREAS IN THE HULL FORM/HYDRODYNAMIC CATEGORY HAVE BEEN IDENTIFIED

Three program areas in the hull form/hydrodynamic category have been identified:

- Submerged air cushion (SAC)
- The cutaway hull (CH)
- Tunnel sterms (TS).

Each of these program areas is discussed below.

(1) Submerged Air Cushion

The submerged air cushion replaces a portion of the hull/water interface with an air/water interface which effectively eliminated the frictional resistance for that portion of the hull. In actual application, the flat of the ship's bottom is recessed, as shown in Figure C-1, and the cavity formed is filled with air.

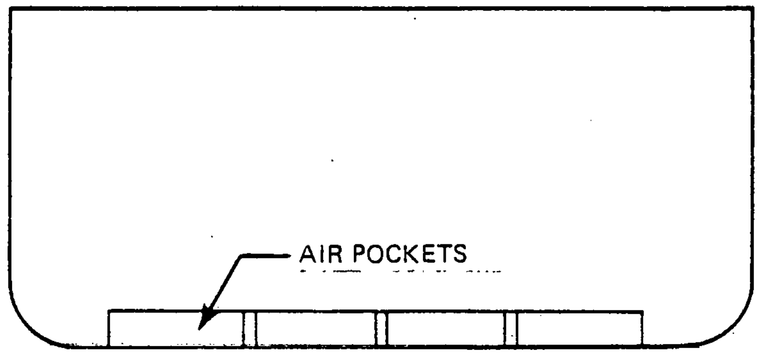


FIGURE C-1
Submerged Air Cushion Hull Form Cross Section

Research into the submerged air cushion concept has been going on since the early 1900's. However, there are two primary reasons why these early efforts have failed:

- Subsurface wave conditions affect the ability of the vessel to maintain the air cushion, and only deep draft ocean going vessels (approximately 100,000 DWT or larger have drafts deep enough to insure maintenance of the air cushion

- Previous work has relied on high pressure/ high volume fans which resulted in complex and impracticable systems.

A nontechnical reason makes the SAC attractive at this time. Mandatory double bottom requirements are now under consideration by Congress and the Coast Guard as a means of reducing the pollution hazard of ocean transport of oil. However, if as in the SAC hull form, the bottom shell is recessed away from the baseline of the vessel, the safety effect is quite similar to that offered by the double bottom.

Recent model tests in England of a 200,000 DWT tanker have indicated that a reduction in resistance, as shown in Table C-1, is possible.

Table C-1
Reduction in Resistance for a 200,000 DWT SAC Tanker As a Percentage of Total Resistance

SPEED	STILL WATER	CALM WATER	15 FOOT WAVES
14	20.4	18.8	16.8
15	20.0	18.5	16.5
16	20.0	18.5	16.5
17	18.4	16.7	15.0
20	12.0	10.8	9.8

Source: "The Submerged Air Cushion (SAC) Vessel - The Application of the Air Cushion Principle to Very Large Vessels - The Case for Further Research," J.W. Grundy.

1. Applications

The submerged air cushion was applied to the generic U.S. flag 150,000 DWT tanker. The horsepower level, acquisition costs and maintenance and repair costs were varied, as shown in Table C-2.

Table C-2
Changes to Baseline Operational and Cost Parameters for Submerged Air Cushions

Vessel Type	DWT	Horsepower		Acquisition Costs (Millions of $)		Maintenance and Repair Costs ($/Day)	
		Baseline	SAC	Baseline	SAC	Baseline	SAC
Tanker	150,000	20,000	16,800	68.6	68.5	1,333	1,343

Changes to the baseline operational and cost parameters were based on data published in England by individuals involved in research into submerged air cushions. This paper is listed as the source for Table C-1.

2. Program Elements

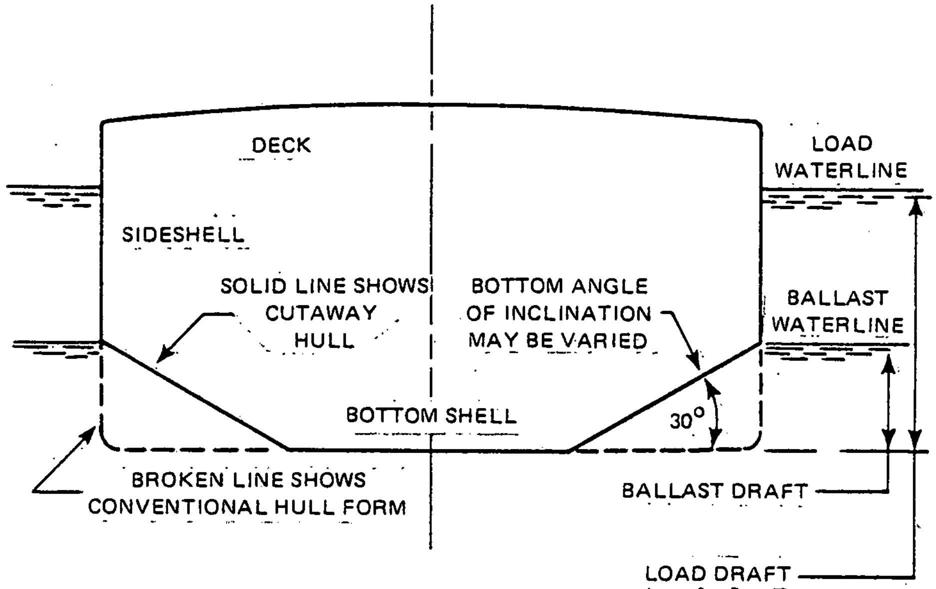
Additional work in this area concerned with:

- Effect of a SAC on stopping
- Effect on maneuvering
- Ability to maintain the air cushion in high sea states
- Effect of trade route on required air cushion depth
- Minimum vessel size or draft required to make the SAC effective

is required prior to a serious consideration of the SAC for a demonstration project. Estimated program costs are approximately $400,000 to cover additional technical studies and model tests.

(2) Cutaway Hull

Recent regulations promulgated by the Inter-governmental Maritime Consulative Organization (IMCO), a branch of the United Nations and contemplated actions by the United States Coast Guard, may result in the requirement that tankers over 20,000 DWT's be fitted with sufficient segregated ballast capacity to allow the tankers to achieve a ballast draft of approximately 38 percent of their full load draft. This will allow the vessels to achieve a safe operating draft on the ballast leg of a voyage without loading sea water into dirty cargo tanks. The cutaway hull form decreases the tanker's initial buoyancy below the ballast water-line. This reduces the amount of segregated ballast required. The expected gains can be taken either as an increase in speed in either the loaded or ballast condition or a decrease in required horsepower and fuel consumption. The cutaway hull concept is shown in Figure C-2.



SOURCE: MARITIME REPORTER/ENGINEERING NEWS, AUGUST 1976, "CUT TANKER OPERATING COSTS WITH NEW HULL FORM — THE CUTAWAY HULL" DWYER & COMENS

FIGURE C-2
Midship Section Outline of the Cutaway Hull Form

The cutaway hull form is a proprietary concept of the Gulf Oil Corporation and published information has addressed the economic analysis and estimates of increased speed. A model testing program is now underway to verify the estimated speed gains. Many areas remain to be researched including:

- The impact of chine shape
- The impact of chine position
- Optimum bottom angle
- Optimum bow and stern configurations.

Gains other than speed in the ballast condition are expected. They are:

- Increased grounding protection due to the removal of the bilge region

- Reduced internal area of ballast tanks subject to sea water corrosion

- Speed gain in the loaded condition
- Reduced structural weight.

Preliminary estimates of changes in operating parameters are shown in Table C-3.

Table C-3
Comparison of Operational Parameters for Cutaway Hull

ITEM	UNITS	CONVENTIONAL HULL NON-SEGREGATED	CONVENTIONAL HULL-SEGREGATED	CUTAWAY HULL SEGREGATED
DWT	MT	231,400	228,300	228,800
DESIGN DRAFT	M	20.8	20.8	20.8
STEEL WEIGHT	MT	32,400	35,500	32,000
SPEED LOADED	KTS	15.6	15.6	15.6
SPEED BALLAST	KTS	16.5	16.5	17.2
TRANSPORTATION COST	$/MT	9.81	10.01	9.60

Source: Maritime Reporter/Engineering News, August 1976, "Cut Tanker Operating Costs With New Hull Form — The Cutaway Hull," Dwyer & Comens

The results presented in Table C-3 indicate that the cutaway hull achieved the following gains with respect to the conventional approach to providing segregated ballast capability:

- 4 percent increase in ballast speed
- 4 percent decrease in unit transportation costs.

All calculations were carried out with the vessels having an installed shaft horsepower of 32,500 SHP.

1. Application

The cutaway hull was applied to the generic U.S. flag 150,000 dwt tanker. The horsepower level and acquisition costs were varied as shown in Table C-4.

Table C-4
Changes to Baseline Operational and Cost Parameters for Cutaway Hulls

Vessel Type	DWT	Horsepower		Acquisition Costs (Millions of $)	
		Baseline	CH	Baseline	CH
Tanker	150,000	20,000	18,800	68.6	68.4

The changes in the baseline operational and cost parameters were based on data published by the Gulf Oil Corporation.

2. Program Elements

Further optimization work on this concept is required both from an economic and energy conservation standpoint prior to its implementation. A complete model testing program and economic analysis is estimated to cost on the order of $300,000 and require one year for completion

(3) Tunnel Sterns

Tunnel sterns are formed by bringing the afterbody down around the propeller as shown in Figure C-3. Until recently, the tunnel stern has been used almost exclusively in inland river applications where high power levels and draft restrictions combine to require a propeller diameter that is greater than the draft of boat.

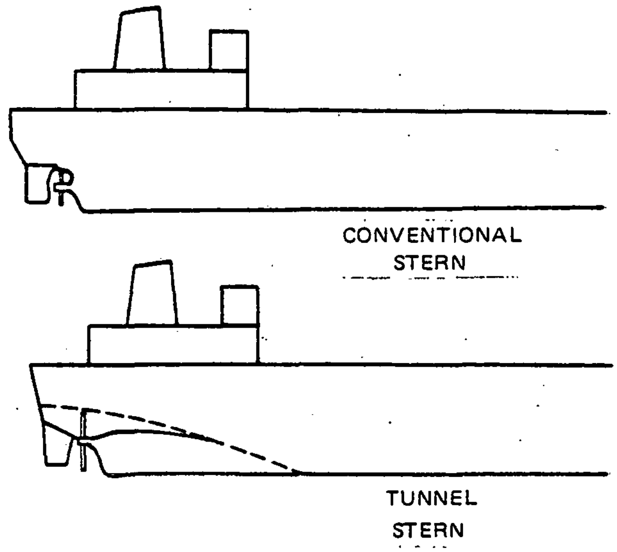


FIGURE C-3
Conventional and Tunnel Sterns

In the inland rivers, the minimum channel depth in commercial navigable waterways is nine feet. River towboats sometimes have propellers with diameters over nine feet. In order to keep the propeller submerged, the propeller is placed in a close fitting semiduct that entrains water from the side and bottom of the vessel and lifts it up and over the propeller.

In order to take advantage of increased propeller efficiency offered by a larger, slower turning propeller, Burmeister and Wain Shipyard in Copenhagen, Denmark, have modified their standard 60,000 DWT PANAMAX bulk carrier design to incorporate a tunnel stern. Patents covering this application have been applied for. Four major changes were made in the original design to produce an overall 30 percent reduction in fuel consumption:

- New bow design
- Tunnel stern
- Increase in propeller disk area of 100 percent (diameter increased from 6.35 m to 9 m)
- Reduction of propeller RPM (from 140 to 50).

This spectacular decrease in fuel consumption must be viewed with some caution. In large bulk carriers, propeller RPM's are in the range of 80-100. A relation exists between power and propeller characteristics such that for a given efficiency level as power increases, diameter must increase and RPM decrease. In this instance, B&W have reduced RPM and increased the propeller diameter to achieve higher efficiency. In general, propulsive efficiency is reduced from 3.5 to 5 percent for every ten RPM off the optimum achievable for a given combination of horsepower and propeller diameter. The original propeller RPM of 140 was due to the direct coupling of the main engine (slow speed diesel) to the propeller. This high propeller RPM produced a vessel with a propulsive efficiency lower than similar vessels.

The resistance of the tunnel stern is higher than the conventional open stern, due to increased surface area and frictional drag. Reduced fuel consumption benefits achievable through larger propeller diameters and lower RPM's have generally been too small to offset the added resistance of the tunnel stern.

1. Applications

The tunnel stern was applied to all generic U.S. flag dry bulk vessels, tankers and coastal tankers. Horsepower levels and acquisition costs were varied, as shown in Table C-5.

Table C-5
Changes to Baseline Operational and Cost Parameters for Tunnel Sterns

		Horsepower		Acquisition Costs ($/Day)	
Vessel Type	DWT	Baseline	TS	Baseline	TS
Dry Bulk	20,000	8,000	7,600	8.0	8.5
Dry Bulk	30,000	10,000	9,500	14.0	14.6
Dry Bulk	40,000	11,000	10,450	20.2	20.9
Tanker	20,000	7,000	6,550	8.0	8.5
Tanker	40,000	9,000	8,550	20.2	20.8
Tanker	65,000	14,000	13,300	27.0	27.8
Tanker	80,000	16,000	15,200	31.0	31.8
Tanker	150,000	20,000	19,000	68.6	69.6
Coastal Tanker	40,000	12,000	11,400	20.2	20.9

The changes to the baseline operational and cost parameters are estimates based on interviews conducted over the course of this study.

2. Program Elements

The exact nature of the interrelationship between the:

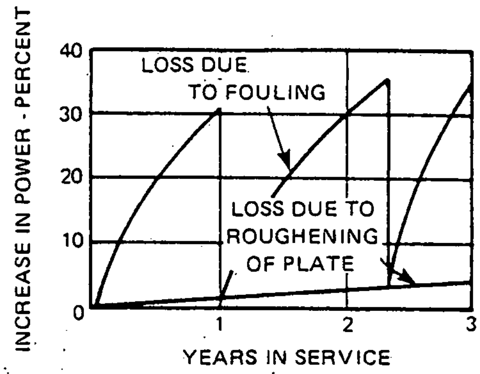
- Increased costs due to a larger propeller and other equipment changes, such as propeller shaft, larger reduction gears, etc.
- Operational cost savings due to reduced fuel consumption
- Increased efficiency of the propulsive system
- Increased resistance of the hull

are unknown at present. An investigation into the applicability of the tunnel stern to ocean going vessels is needed before the conservation potential of this concept can be evaluated. A program on the order of $300,000 and a years duration is required for the necessary model tests and technical and economic analysis.

2. ONE PROGRAM AREA IN THE HULL MAINTENANCE/HYDRODYNAMICS CATEGORY HAS BEEN IDENTIFIED

The effects of hull roughness on the economic and energy use patterns of vessel operations is significant. One program addressing the area of hull maintenance and smoothing has been identified.

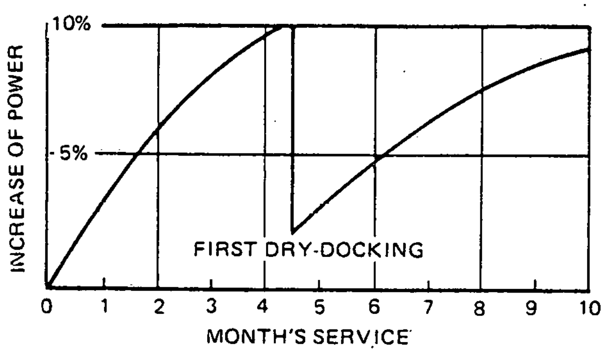
The effect of hull fouling and corrosion on a vessel's fuel consumption is tremendous. Increases in the power required to maintain a given speed can range up to 30 percent per year as shown in Figure C-4. These are the results of full-scale tests carried out on the Koningan Elisabeth, a cross-channel type vessel.



Source: "Effects of Bottom Maintenance on Functional Resistance of Ships," Society of Naval Architects and Marine Engineers, Technical and Research Report R-18.

FIGURE C-4
Loss in Performance With Time in Service for Cross-Channel Ship "KLONINGAN ELISABETH"

The trends shown in Figure C-4 were confirmed with full-scale tests of the MV JORDEANS. These results are shown in Figure C-5.



Source: "Effects of Bottom Maintenance on Functional Resistance of Ships," Society of Naval Architects and Marine Engineers, Technical and Research Report R-18.

FIGURE C-5
Loss in Performance With Time in Service for the MV JORDEANS

As can be seen, the added increase in resistance can be attributed to two effects:

- Fouling
- Corrosion.

Prior to the energy crisis of 1974, which precipitated the dramatic rise in fuel prices, the common commercial practice was to dry dock a vessel only when classification society and insurance consideration required it, with inspections generally occurring at 12-month intervals. The development and approval of underwater survey techniques, however, have increased the time period between required dry dockings from 12 to 18, and sometimes 30 months.

The increased resistance overtime due to fouling is dependent upon the operational profile of a given ship. The most important factors which determine the fouling rate are:

- Area of service
- Speed of the vessel
- Water conditions at the docking or anchorage location.

It has been shown that marine organisms will not attach themselves in water that:

- Has a velocity greater than three to four feet per second
- Is polluted or brackish.

Colder water temperatures also inhibit marine fouling. In addition, there are specific "seasons" where high rates of fouling occur.

Due to the many variables that determine the fouling rate, there is a tremendous degree of variation in hull maintenance practices. These range from the operator who only cleans the hull during surveys to individual companies whose hull maintenance programs are highly sophisticated. An example of the latter is Sea-Land, a United States flag containership operator who does not apply antifouling paints to vessels operating in the North Atlantic, as the service patterns and harbor water conditions are such that fouling is minimized.

In a recent technical and research report* (R-18), the Society of Naval Architects and Marine Engineers recommended the development of optimum hull maintenance programs for vessels by trade area. This suggestion is adopted by this report. The areas to be covered by any research effort should address:

- Expected rate of fouling by ship type and trade area
- Effectiveness of in-water cleaning techniques
- Development of a general methodology to predict optimum time spans between dry dockings and/or in-water cleaning.

It has been found that surface roughness due to corrosion, improperly applied paints and poor surface preparation, can cause resistance increases of up to 30 percent, even in the absence of visible fouling. A paper by the British Ship Research Association contained an estimate of a horsepower allowance needed for hull roughness and is given in Table C-6.

Table C-6
Increased Horsepower Required Due to Surface Roughness

MEAN ROUGHNESS VALUE, IN.	APPROXIMATE ALLOWANCE ON TRIAL SHP PER CENT
0.0050	+ 0
0.0060	+ 3
0.0070	+ 6
0.0080	+ 9
0.0090	+12
0.0100	+15
0.0120	+21
0.0140	+25
0.0160	+28
0.0180	+30
0.0200	+32

Source: Lynn, W.M., "Trial-Performance Results and Hull Surface Roughness Measurements for 18,000 DWT Tankers," BSRA Report No. 267, 1961.

* "Effects of Bottom Maintenance on Functional Resistance of Ships," Society of Naval Architects and Marine Engineers, Technical and Research Report R-18.

Figure C-6, published by the Norwegian Ship Research Institute, shows the expected increase in resistance due to corrosion over time. This data was taken from actual surface roughness measurements of vessels in service.

This increase in surface roughness and fuel consumption is expected by vessel operators. Recently, the International Paint Company, Inc., introduced a new antifouling paint system called SPC (self-polishing copolyner)*, which polishes itself to a smooth surface as the vessel moves through the water. SPC differs from conventional antifoulants in the way the biocide is released:

- Conventional antifoulants leach biocides into the seawater. The leaching rate is exponential with extremely high release rates at the beginning followed by much lower release rates towards the end of the coatings life.

- SPC actually removes itself over the life of the coating so that an active surface is always present.

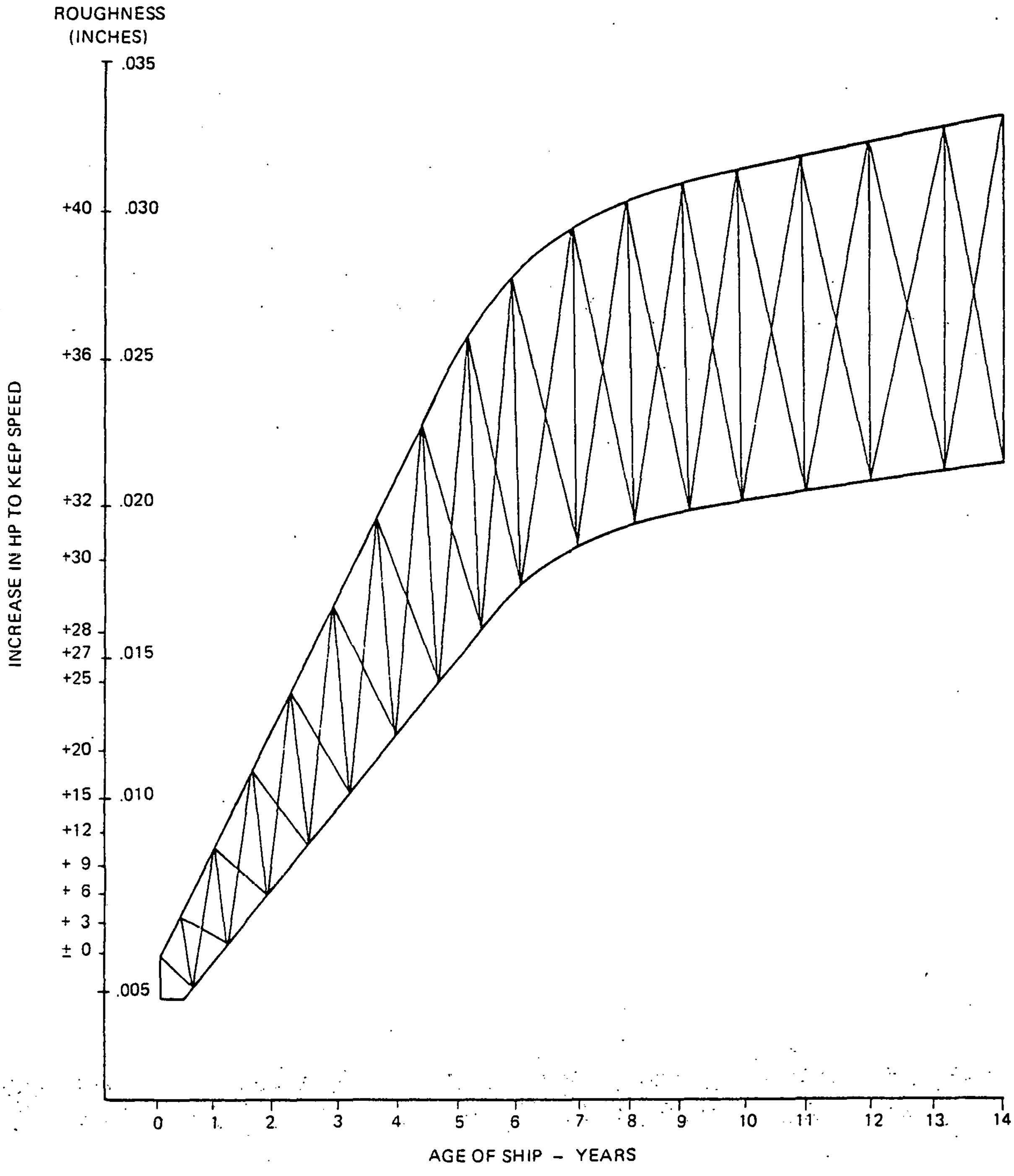
In addition, the polishing action takes place more rapidly in areas of high turbulence which results in a smoothing of the paint film. Results of full-scale applications show an actual decrease in resistance over time as the hull surface polishes itself.

Lack of EPA certification has precluded the use of SPC in the United States. Two formulations of SPC are available, and they differ in the type of biocide used. The first formulation developed by International Paints contained a highly toxic biocide that is banned in the United States. Subsequently, a second formulation was developed, however, EPA certification has not been received, and the paints are not available in the United States.

(1) <u>Applications</u>

Hull smoothing and maintenance programs were applied to all generic U.S. flag ocean going vessels. Horsepower levels, acquisition costs, and maintenance and repair costs were varied, as shown in Table C-7.

Changes to the baseline operational and cost parameters were based on information received from the International Paint Company. In some cases, the



Source: Norwegian Ship Research Institute

FIGURE C-6
Increase in Plate Roughness and Power Requirements Over Time

Table C-7
Changes to Baseline Operational and Cost Parameters for Hull Maintenance and Smoothing Programs

Vessel Type	DWT	Horsepower		Acquisition Costs (Millions of $)		Maintenance and Repair Costs ($/Day)	
		Baseline	HMS	Baseline	HMS	Baseline	HMS
Container	12,000	8,000	7,360	16.1	16.1	500	550
Container	16,500	17,000	15,640	32.2	32.1	750	814
Container	18,500	18,000	16,560	43.1	43.1	827	895
Container	23,000	28,000	25,760	47.4	47.2	1,028	519
Ro/Ro	16,500	22,000	20,240	38.0	38.0	750	1,161
Barge Carrier	33,000	33,000	30,360	53.0	52.9	899	1,007
Barge Carrier	42,000	38,000	34,960	57.0	57.1	1,334	1,460
Breakbulk	13,500	14,500	13,340	30.0	29.9	746	800
Tramp	8,400	5,000	4,600	18.7	18.7	508	544
Dry Bulk	20,000	8,000	7,360	8.0	8.0	527	933
Dry Bulk	30,000	10,000	9,200	14.0	13.9	803	886
Dry Bulk	40,000	11,000	10,120	20.2	20.3	899	996
Tanker	20,000	7,000	6,440	8.0	8.0	870	933
Tanker	40,000	9,000	8,280	20.2	20.3	899	996
Tanker	65,000	14,000	12,880	27.0	27.1	994	1,122
Tanker	80,000	16,000	14,720	31.0	31.2	1,160	1,310
Tanker	150,000	20,000	18,400	68.6	68.9	1,333	1,530
Coastal Tanker	40,000	12,000	11,040	20.2	20.3	899	996

reduction in acquisition cost due to a smaller main propulsion plant was exactly offset by increased costs due to the more advanced paint systems, resulting in no change to the acquisition costs.

(2) Program Elements

Research into the field of hull roughness has been suggested by the Society of Naval Architects and Marine Engineers to include the following:

- Develop standard measurement techniques and equipment to describe hull surface profiles. These should be able to be used under water.

- Correlate in-service speed losses with surface roughness, time and operating and dry dock costs

- Develop hull and propeller maintenance procedures to reduce drag more effectively than available with current surface preparation and painting methods.

Based on these recommendations, an investigation into maintenance procedures, their costs and effectiveness is needed prior to funding additional work in this area. A study to:

- Correlate in-service speed losses, increased fuel consumption, lost time, operating costs and dry docking and cleaning costs

- Identify and evaluate currently available hull maintenance programs and equipment

- Identify, evaluate and develop recommendations for areas of further work

is estimated at $250,000 and one year's duration.

APPENDIX D

VESSEL OPERATIONS

APPENDIX D

VESSEL OPERATIONS

The potential for fuel conservation through changes in operating practices was examined in two subcategories:

- Vessel routing (VR)
- Vessel operations (VO).

Each of these is discussed below.

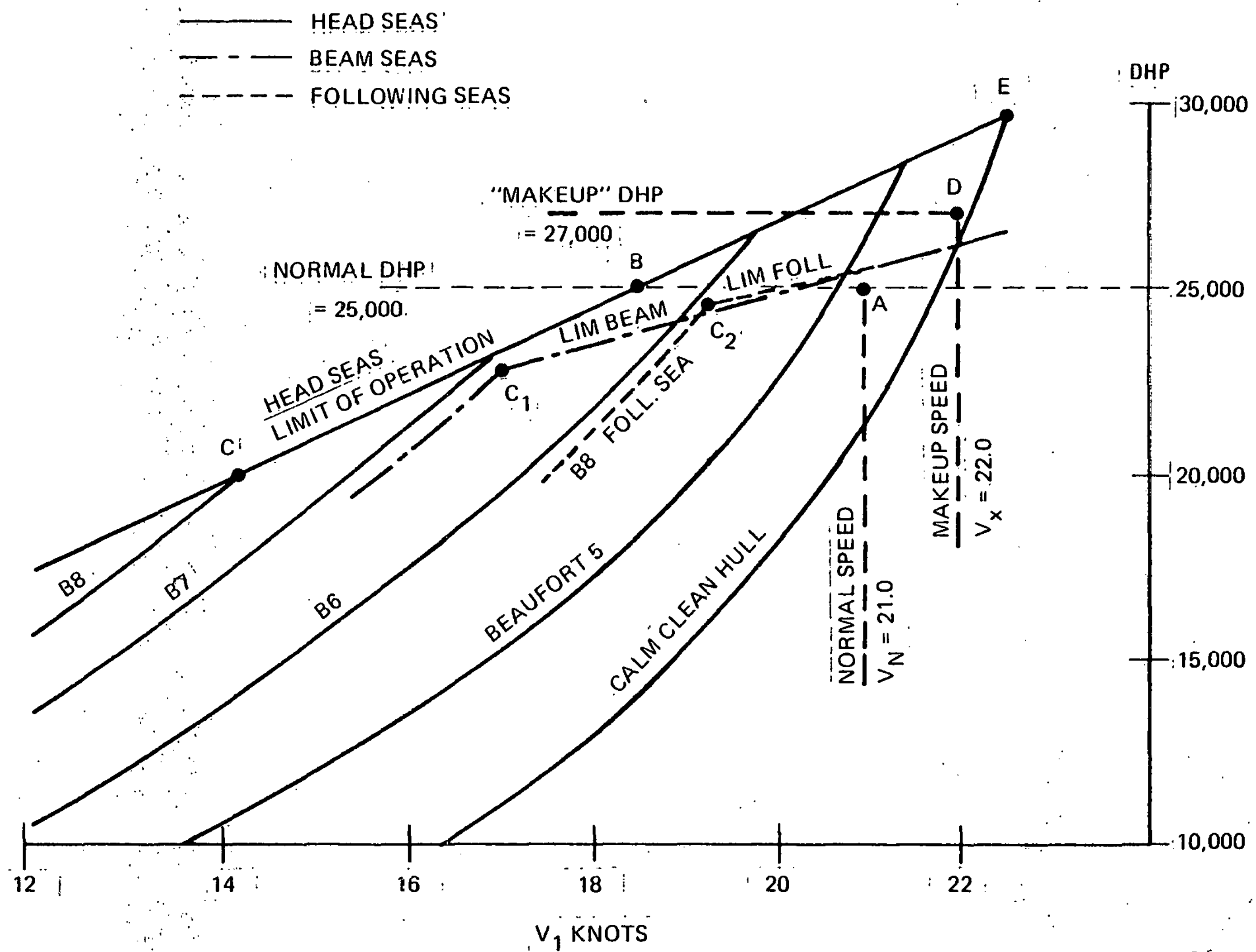
1. VESSEL ROUTING

The economics and fuel conservation potential of weather routing have been recognized for some time. After fouling, the single most important factor that affects the vessel's ability to make a given speed at a specified horsepower is weather conditions. Figure D-1 shows the relationship of sea state (as measured on the BEAUFORT scale), on speed and horsepower for the containership DART EUROPE.

Point "A" in Figure D-1 represents calm water speed (21 knots) at normal power levels. As the weather increases, speed is reduced until point "B" is reached. At this time, power must be reduced and the maximum speed that the vessel is able to make, for given sea conditions, follows the line B-C. Zubley, in his analysis, examined the fuel consumption patterns and time-speed-distance relationships associated with a series of hypothetical cases where a vessel:

- Enters a storm and:
  - Maintains course at head seas
  - Alters course at 15° increments throughout the storm
- Alters course 24 hours prior to entering the storm in order to avoid it entirely.

A primary assumption made was that all time lost due to slowing of the vessel due to weather or additional time consumed by the avoidance case was made up by later operations at higher speeds.



Source: "Optimizing Fuel Consumption in Heavy Weather Service," Zubley & Lewis, technical memorandum, Center for Maritime Studies, Webb Institute of Naval Architecture, Dec. 1976.

FIGURE D-1
Service Performance of the DART EUROPE

Specific conclusions reached in regard to the hypothetical vessel were:

- No reduction in fuel consumed/voyage if a change of course was made after a storm was encountered.
- A distinct fuel savings was found to be achievable if the vessel avoided the storm and sufficiently accurate sea state predictions were available. The larger the storm, the greater the fuel savings potential.

The fuel savings achieved, as calculated by Zubley, are shown in Table D-1. With a daily fuel consumption of approximately 100 long tons, the savings are modest.

Table D-1
Fuel Saved by a 25,000 SHP, 21 Knot Containership
by Going Around Vs. Going Through a Storm

	STORM SIZE, NAUTICAL MILES		
	200	400	600
LONG TONS OF FUEL SAVED	13.4	43.4	54.3

Source: "Optimizing Fuel Consumption in Heavy Weather Service," Zubley & Lewis technical memorandum Center for Maritime Studies, Webb Institute of Naval Architecture, Dec. 1976.

The real potential for weather routing appears to be in reduced time underway, less cargo damage, less hull damage and reduced probability of total loss due to weather.

Weather routing services are presently available with Ocean Routes, Inc., currently providing weather routing services to 800 of the 1,200 vessels currently being weather routed each month. Forecasts are available worldwide on grid coordinates 2.5 degrees apart for up to 72 hours. At the current time, approximately 20 percent of all vessels making transocean crossings are weather routed. Due to the small energy savings potential offered by vessel weather routing, this program was not evaluated further.

2. OPERATING PROCEDURES

Vessel operations offer a greater potential for realizing significant fuel savings. An example of one operator's experience is discussed.

In 1973, Chevron Shipping initiated a fuel conservation program through better operating practices. Chevron shipping operates a fleet of 70 steam powered tankers whose yearly fuel consumption is approximately 15 million barrels. Chevron selected six experienced chief engineers from their fleet to act in the capacity of superintending engineers, and ride vessels to carry out the program. The fuel savings goal was 5 percent, established primarily as a result of early findings. The results of the program showed a potential for fuel savings, fleetwide, as shown in Table D-2. These conservation estimates were considered conservative by Chevron.

Table D-2
Potential for Fuel Conservation
Due to Operational Practices

ITEM	% FUEL CONSUMPTION REDUCTION
REDUCTION OF EXCESS AIR	1.1%
OPTIMIZE SYSTEM HEAT BALANCE	0.6%
OPERATE BOILERS AT DESIGN CONDITIONS	0.7%
OPERATE AT DESIGN VACUUM	0.4%
REDUCE HEAT STEAM & CONDENSATE LOSSES	0.3%
REDUCE HOTEL LOADS	0.3%
REDUCE CARGO AND FUEL HEATING	0.7%
IMPROVE CARGO PUMPING OPERATIONS	0.5%
IMPROVE TANK CLEANING OPERATIONS	0.4%
IMPROVED SHIP HANDLING	0-6% BUT USUALLY INDETERMINABLE

Source: Marine Fuels Energy Conservation Program for Steam Turbine Ships, Chevron International Co.

The extent to which similar conservation programs have been carried out throughout the U.S. flag fleet is unknown. However, a recent informal poll of U.S. Maritime Academy cadets, returning to school after their summer cruise, indicated that the automatic data logging and plant monitoring equipment originally installed on newer U.S. flag vessels was either not working, or if the equipment was working, very little was being done with the data generated. In the case of older vessels, many had torsion meters that were inoperable or poorly calibrated. This indicates a need to motivate U.S. flag operators to develop, implement and maintain fuel conservation programs.

(1) Application

A vessel operations program was evaluated by applying an across-the-board specific fuel consumption reduction of approximately 4 percent to all generic U.S. flag steam driven vessels. This reduction was based on the results achieved by Chevron Shipping in their fuel conservation program.

(2) Program Elements

A vessel operations program should consist of an educational effort aimed at the operators to inform them of the conservation potential of increased operational management attention. Due to the dramatic increases in fuel prices, this educational effort has already started with the publication of numerous technical papers addressing operational conservation. No active ERDA-funded program in this area is anticipated.

APPENDIX E

FUELS

APPENDIX E

FUELS

The generic technology area of fuels can be subdivided into two main categories:

- Contingency fuels
- Alternative fuels.

Each of these categories is the subject of separately funded studies and will be discussed only briefly in this report.

The difference drawn between the two categories is based on the ease with which the fuels can be introduced into the commercial marine transportation industry. Contingency fuels are those that can be used to extend current fuel supplies and burned in existing engines or boilers with minor modifications. Alternative fuels are those that are truly different from the crude petroleum-based residual and diesel fuels in use today. Their use would require the establishment of logistic networks and major modification to existing engines prior to their use. Each of these areas is discussed in greater detail below.

1. CONTINGENCY FUELS

Contingency fuels are those which can be used in current diesel and marine boilers to either extend or replace entirely the residual and diesel fuels now used. A critical criteria that must be satisfied is the ability to change between existing and contingency fuels quickly, with little or no changes to the engines. Techniques or equipment that will allow the engines to burn lower grade fuels are also to be considered here.

The United States has extensive stocks of two base resources that could be used to produce nonpetroleum-based liquid hydrocarbon fuels:

- Oil shale
- Coal.

In addition to these two sources of fuel stocks, tar sands exist outside the United States and U.S. flag vessels could conceivably bunker with fuel oils derived from tar sands in foreign ports. Liquid fuels are considered prime contingency fuels as compatibility with existing fuel storage and handling systems is a requirement for this category.

Coal/oil slurries have been studied as contingency fuels by the British and Germans since World War I. Coal/oil slurries were used by the British in 1932 on the liners "Scythia" and "Berengaria." German tests were conducted at approximately the same time. These experiments were for the purpose of determining a fallback fuels position in the event that petroleum fuels became limited in wartime.

It has also been reported* that coal/oil slurries were used successfully in a diesel engine in 1936. However, the location and results of this experiment have not been determined.

Emulsions of oil/water offer potential for substituting residual fuels for the higher distillates now in use in medium and high speed diesel engines. In some cases, oil/water emulsions have improved the fuel consumption at off peak loading conditions. In addition, emissions of unburned hydrocarbons and NO_x have been reported as being reduced. Use of oil/water emulsions in marine boilers is now undergoing tests sponsored by the Maritime Administration. Preliminary findings indicate good results in reducing excess air and elimination of slagging in some boilers.

These three areas — synfuels, coal/oil slurries and oil/water emulsions — both separately and in various combinations, offer high potential for use as contingency fuels.

2. ALTERNATIVE FUELS

Alternate fuels are all nonhydrocarbon fuels or nonliquid hydrocarbon fuels. Within this categorization fall the following energy sources:

- Wind
- Solar
- Nuclear
- Hydrogen.

Of these four sources, it appears that the first three will provide indirect power through the production of hydrogen

* Alternative Assessments of the Potential for Colloidal Fuels, A.F. Garcia, TetraTech Inc., report dated June 19, 1975.

based or nonhydrocarbon based fuels that will most likely be used to power ships after depletion of naturally occurring hydrocarbon fuels.

A study recently completed by the University of Michigan has indicated that in some instances where schedule adherence is not of prime importance, wind driven merchant ships could be economically attractive in the future. These applications will, for the most part, be specialized cases due to their reliance on wind, and the need to provide an auxiliary power plant.

Solar power is not a practicable direct marine power source, due to the large space requirement. A 10,000 h.p. plant will require approximately 1.88 million ft^2 of collector surface and large battery storage capability. At present, the largest merchant ship, a 500,000 dwt tanker, has approximately one-quarter million square feet of deck space and a power requirement of approximately 40,000 to 50,000 h.p.

Nuclear power systems have potential, however, due to the requirement for highly trained operating personnel and many regulatory and licensing constraints, merchant vessel applications will be extremely limited.

Hydrogen, in the form of hydrazine (N_2H_4) or ammonia seems to offer the most potential for commercial merchant vessel applications. Use of hydrogen can take one of three different forms:

- Direct conversion of hydrogen into heat in boilers or internal combustion engines
- Use of hydrogen in fuel cells, either a Bacon or Neidrack
- Use of hydrogen in the form of hydrazine in a hydrazine/air fuel cell.

Use of hydrogen in its gaseous form creates storage, handling and safety problems that will most likely prevent its use in merchant ships.

Hydrogen fuels cells are more attractive than direct conversion. The Bacon cell requires oxygen for the oxidant where the Neidrach cell uses air.

Hydrazine is a heavy liquid that can be handled very similarly to commercially available fuels. For this reason, ease of use, hydrazine is considered a promising alternative fuel. Its use in an air/hydrazine fuel cell is possible and cells having weights of 18 lb./kw have been tested reaching efficiencies of 68 percent.

APPENDIX F

GENERIC U.S. FLAG BASELINE OPERATIONAL AND COST PARAMETERS

Table F-1
Generic U.S. Flag Baseline Operational and Cost Parameters

Industry Sector	Generic Vessel Type	DWT Long Tons	HP	Speed in Knots (MPH)	Utilization Factor %	Full Rate lb/shp-hr.	Fuel Type	U.S. Costs (millions)	$/Day			
									Wages	Stores Subsistance Costs	M&R	Insurance
Foreign Trade	Container	12000	8000	16	50	.47	R	16.1	3146	100	500	750
		16500	17000	20	50	.47	R	32.2	3993	100	750	1022
		18500	18000	20	50	.47	R	43.1	4462	559	827	1022
		23000	28000	23	50	.47	R	47.4	4542	495	1028	1781
	Ro/Ro	10000	11000	24	33	.47	R	23.8	3993	100	750	1022
		16500	22000	22.5	33	.47	R	38.0	4008	449	1090	1635
		18000	25000	22.5	33	.47	R	42.8	4008	449	1090	1635
	Barge carriers	33000	33000	22	60	.47	R	53.0	2942	424	899	822
		42000	38000	22	60	.47	R	57.0	5649	751	1334	1639
	Break bulk	13500	14500	19	40	.47	R	30.0	5718	706	746	1025
	Tramp	8400	5000	14	40	.47	R	18.7	3995	442	508	348
	Dry bulk	20000	8000	15	96	.47	R	8.0	3748	428	527	482
		30000	10000	15	96	.47	R	14.0	2942	399	803	732
		40000	11000	15	96	.47	R	20.2	2942	424	899	822
	Tanker	20000	7000	14	96	.47	R	8.0	4024	487	870	436
		40000	9000	14	96	.47	R	20.2	2942	424	899	822
		65000	14000	15	96	.47	R	27.0	3121	457	994	940
		80000	16000	15	96	.47	R	31.0	3121	499	1160	1211
		150000	20000	15	96	.47	R	68.6	3200	551	1333	1608
Inland	Tow boat		1350	(7.2)	–	.37	D	.84	362	67	42	21
Coastal	Coastal tanker	40000	12000	15	96	.47	R	20.2	2942	424	899	822
	Coastal tug	–	2000	8	–	.37	D	1.0	362	80	51	25
	Coastal freighter	7800	6000	15.5	50	.47	R	16.0	2904	100	375	562
Great Lakes	G.L. tug	–	900	(9)	–	.37	D	.56	362	33	33	16
	G.L. dry bulk	16700	4860	(12)	96	.47	R	15.6	2440	659	629	1081
		14900	4180	(12)	96	.37	D	13.9	2440	679	649	963
		13100	2550	(12)	96	1.24	Coal	12.2	2440	659	629	845
	Tanker	6576	1925	(12)	96	.47	R	3.9	650	90	120	142
		2676	1410	(12)	96	.37	D	1.6	650	90	110	58
Offshore	Offshore tug	–	4000	14	–	.37	D	2.5	568	93	79	40
	Offshore tug/supply	–	3300	15	–	.37	D	2.5	464	90	65	35
	Offshore supply	–	3300	13	–	.37	D	2.0	464	90	65	35
	Offshore crew boat	–	1800	25	–	.37	D	.5	464	90	35	20

APPENDIX G

SAMPLE MODEL OUTPUT

Table G-1
Baseline, Vessel Operating and Cost P ameters -
23,000 DWT Containership, Trade Route 21
Gulf Coast/Western Europe

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)

TYPE	CONTAINER US FLAG	
DWT	23000. LONG TONS	
HORSEPOWER	28000.	
TYPE OF FUEL	RESIDUAL	
DESIGN SPEED	23.0 KNOTS	
FUEL CONSUMPTION		
AT DESIGN SPEED	141. LTON/DAY	(.47 LB/SHP-HR)
IN PORT	16. LTON/DAY	

SERVICE CHARACTERISTICS

SERVICE	TR 21 GULF/W EUROPE
SPEED, KNOTS	23.0
ROUND TRIP TIME, DAYS	23.1
AT SEA	18.1
IN PORT	5.0
AVERAGE DISTANCE, N MI	10000.
CARGO PER HAUL, LT	11500.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS		
AT SEA	2554.	
IN PORT	78.	
TOTAL	2632.	(109115.988 MBTU)

COST SUMMARY

VESSEL COSTS	318076.	
PORT COSTS	1250.	
CARGO COSTS	345000.	
TOTAL DIRECT COST		664326.
GEN + ADMIN	166081.	
TOTAL OPERATING COST		830407.

SUMMARY FOR ONE YEAR

VOYAGES	14.3	
CARGO HAULED, LT	164172.	
FUEL USED, LT	37580.	
TOTAL OPERATING COSTS		11854780.

Table G-2
Baseline, Financial Performance - 23,[illegible] DWT
Containership, Trade Route 21
Gulf Coast/Western Europe

CAPITALIZATION SCHEME

METHOD	TITLE XI
FULL CAPITAL COST	23700000.
INITIAL INVESTMENT	4740000.
DEBT SERVICE/LEASE PMT	1931118.
ANNUAL INTEREST RATE	.080
CORPORATE TAX RATE	.48

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL(SEA)	FUEL(PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	19776.	7067.	10904.	14543.	3395043.	103628.	17845.	4925172.	8493979.	2123495.	1931118.	12548591.
2	20765.	7420.	11449.	15270.	3564795.	108809.	18737.	5171431.	8918678.	2229669.	1931118.	13079465.
3	21804.	7791.	12022.	16034.	3743035.	114250.	19674.	5430003.	9364611.	2341153.	1931118.	13636882.
4	22894.	8180.	12623.	16836.	3930187.	119962.	20658.	5701503.	9832842.	2458210.	1931118.	14222170.
5	24038.	8589.	13254.	17677.	4126696.	125961.	21690.	5986578.	10324484.	2581121.	1931118.	14836723.
6	25240.	9019.	13917.	18561.	4333031.	132259.	22775.	6285907.	10840708.	2710177.	1931118.	15482003.
7	26502.	9470.	14612.	19489.	4549682.	138871.	23914.	6600202.	11382744.	2845686.	1931118.	16159547.
8	27828.	9943.	15343.	20464.	4777166.	145815.	25109.	6930212.	11951881.	2987970.	1931118.	16870969.
9	29219.	10441.	16110.	21487.	5016025.	153106.	26365.	7276723.	12549475.	3137369.	1931118.	17617962.
10	30680.	10963.	16916.	22561.	5266826.	160761.	27683.	7640559.	13176949.	3294237.	1931118.	18402304.
11	32214.	11511.	17761.	23689.	5530167.	168799.	29067.	8022587.	13835796.	3458949.	1931118.	19225863.
12	33825.	12086.	18649.	24874.	5806676.	177239.	30521.	8423716.	14527586.	3631896.	1931118.	20090600.
13	35516.	12691.	19582.	26118.	6097010.	186101.	32047.	8844902.	15253965.	3813491.	1931118.	20998574.
14	37292.	13325.	20561.	27424.	6401860.	195406.	33649.	9287147.	16016663.	4004166.	1931118.	21951947.
15	39156.	13991.	21589.	28795.	6721953.	205176.	35332.	9751504.	16817497.	4204374.	1931118.	22952989.
16	41114.	14691.	22669.	30234.	7058051.	215435.	37098.	10239080.	17658371.	4414593.	1931118.	24004082.
17	43170.	15425.	23802.	31746.	7410953.	226207.	38953.	10751034.	18541290.	4635323.	1931118.	25107730.
18	45328.	16197.	24992.	33333.	7781501.	237517.	40901.	11288585.	19468355.	4867089.	1931118.	26266561.
19	47594.	17006.	26242.	35000.	8170576.	249393.	42946.	11853015.	20441772.	5110443.	1931118.	27483333.
20	49974.	17857.	27554.	36750.	8579105.	261863.	45093.	12445665.	21463861.	5365965.	1931118.	28760944.

REQUIRED REVENUES

PRESENT VALUE OF INCOME STREAM	190223033.
AVERAGE/INITIAL ANNUAL REVENUE	17939478.
AVERAGE/INITIAL RFR	109.2722

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR	NET REVENUE	NPV-NT RV
1	8493979.	1931118.	2214725.	4740000.	14763316.	1191194.	1516800.	17939478.	109.	3176162.	3176162.
2	8918678.	1931118.	1975816.	0.	15055280.	1191194.	1483655.	17939478.	109.	2884197.	5846715.
3	9364611.	1931118.	1725438.	0.	15362320.	1191194.	1447858.	17939478.	109.	2577158.	8056212.
4	9832842.	1931118.	1463057.	0.	15685227.	1191194.	1409197.	17939478.	109.	2254251.	9845709.
5	10324484.	1931118.	1188113.	0.	16024836.	1191194.	1367443.	17939478.	109.	1914642.	11253028.
6	10840708.	1931118.	900024.	0.	16382027.	1191194.	1322349.	17939478.	109.	1557451.	12313003.
7	11382744.	1931118.	598179.	0.	16757727.	1191194.	1273647.	17939478.	109.	1181751.	13057706.
8	11951881.	1931118.	281944.	0.	17152913.	1191194.	1221050.	17939478.	109.	786565.	13516659.
9	12549475.	1931118.	-49346.	0.	17568616.	1191194.	1164244.	17939478.	109.	370862.	13717025.
10	13176949.	1931118.	-396382.	0.	18005922.	1191194.	1102895.	17939478.	109.	-66444.	13683786.
11	13835796.	1931118.	-759887.	0.	18465976.	1191194.	1036637.	17939478.	109.	-526498.	13439916.
12	14527586.	1931118.	-1140613.	0.	18949908.	1191194.	965078.	17939478.	109.	-1010510.	13006525.
13	15253965.	1931118.	-1539344.	0.	19459230.	1191194.	887795.	17939478.	109.	-1519752.	12403011.
14	16016663.	1931118.	-1956900.	0.	19995048.	1191194.	804329.	17939478.	109.	-2055570.	11647182.
15	16817497.	1931118.	-2394131.	0.	20550858.	1191194.	714186.	17939478.	109.	-2619380.	10755385.
16	17658371.	1931118.	-2851926.	0.	21152157.	1191194.	616831.	17939478.	109.	-3212679.	9742615.
17	18541290.	1931118.	-3331208.	0.	21776522.	1191194.	511689.	17939478.	109.	-3837044.	8622618.
18	19468355.	1931118.	-3832941.	0.	22433620.	1191194.	398134.	17939478.	109.	-4494142.	7401991.
19	20441772.	1931118.	-4358125.	0.	23125208.	1191194.	275496.	17939478.	109.	-5185730.	6110267.
20	21463861.	1931118.	-4907802.	0.	23853142.	1191194.	143046.	17939478.	109.	-5913664.	4740000.

Table G-3
Slow Speed Diesel, Vessel Operating and t
Parameters - 23,000 DWT Containership
Trade Route 21, Gulf Coast/Western Europe

SHIP CHARACTERISTICS (REFLECTING ANY USER-SUPPLIED DATA)

TYPE	CONTAINER US FLAG
DWT	23000. LONG TONS
HORSEPOWER	28000.
TYPE OF FUEL	RESIDUAL
DESIGN SPEED	23.0 KNOTS
FUEL CONSUMPTION	
AT DESIGN SPEED	111. LTON/DAY (.37 LB/SHP-HR)
IN PORT	16. LTON/DAY

SERVICE CHARACTERISTICS

SERVICE	TR 21 GULF/W EUROPE
SPEED, KNOTS	23.0
ROUND TRIP TIME, DAYS	23.1
AT SEA	18.1
IN PORT	5.0
AVERAGE DISTANCE, N MI	10000.
CARGO PER HAUL, LT	11500.

SUMMARY FOR ONE VOYAGE

FUEL CONSUMED, LTONS		
AT SEA	2011.	
IN PORT	78.	
TOTAL	2089.	(86587.466 MBTU)

COST SUMMARY

VESSEL COSTS	273096.	
PORT COSTS	1250.	
CARGO COSTS	345000.	
TOTAL DIRECT COST		619346.
GEN + ADMIN	154837.	
TOTAL OPERATING COST		774183.

SUMMARY FOR ONE YEAR

VOYAGES	14.3	
CARGO HAULED, LT	164172.	
FUEL USED, LT	29821.	
TOTAL OPERATING COSTS		11052129.

Table G-4

Slow Speed Diesel, Financial Performance - [illegible] 000 DWT

Containership, Trade Route 21,

Gulf Coast/Western Europe

CAPITALIZATION SCHEME

METHOD	TITLE XI
FULL CAPITAL COST	23650000.
INITIAL INVESTMENT	4730000.
DEBT SERVICE/LEASE PMT	1927044.
ANNUAL INTEREST RATE	.080
CORPORATE TAX RATE	.48

OPERATING COSTS

YEAR	WAGES	SUBSIST	M+R	INSUR	FUEL(SEA)	FUEL(PORT)	PORT DUES	CARGO COST	TOT DIRECT	G+A	DEBT SERV	AN OP COST
1	19776.	7067.	12919.	14511.	2672693.	103628.	17845.	4925172.	7773612.	1943403.	1927044.	11644058.
2	20765.	7420.	13565.	15236.	2806328.	108809.	18737.	5171431.	8162292.	2040573.	1927044.	12129909.
3	21804.	7791.	14244.	15998.	2946645.	114250.	19674.	5430003.	8570407.	2142602.	1927044.	12640052.
4	22894.	8180.	14956.	16798.	3093977.	119962.	20658.	5701503.	8998927.	2249732.	1927044.	13175703.
5	24038.	8589.	15703.	17638.	3248676.	125961.	21690.	5986578.	9448874.	2362218.	1927044.	13738136.
6	25240.	9019.	16489.	18520.	3411109.	132259.	22775.	6285907.	9921317.	2480329.	1927044.	14328690.
7	26502.	9470.	17313.	19446.	3581665.	138871.	23914.	6600202.	10417383.	2604346.	1927044.	14948773.
8	27828.	9943.	18179.	20418.	3760748.	145815.	25109.	6930212.	10938252.	2734563.	1927044.	15599859.
9	29219.	10441.	19088.	21439.	3948785.	153106.	26365.	7276723.	11485165.	2871291.	1927044.	16283500.
10	30680.	10963.	20042.	22511.	4146225.	160761.	27683.	7640559.	12059423.	3014856.	1927044.	17001323.
11	32214.	11511.	21044.	23636.	4353536.	168799.	29067.	8022587.	12662394.	3165599.	1927044.	17755037.
12	33825.	12086.	22096.	24818.	4571213.	177239.	30521.	8423716.	13295514.	3323879.	1927044.	18546436.
13	35516.	12691.	23201.	26059.	4799773.	186101.	32047.	8844902.	13960290.	3490072.	1927044.	19377406.
14	37292.	13325.	24361.	27362.	5039762.	195406.	33649.	9287147.	14658304.	3664576.	1927044.	20249924.
15	39156.	13991.	25579.	28730.	5291750.	205176.	35332.	9751504.	15391219.	3847805.	1927044.	21166068.
16	41114.	14691.	26858.	30167.	5556338.	215435.	37098.	10239080.	16160780.	4040195.	1927044.	22128019.
17	43170.	15425.	28201.	31675.	5834155.	226207.	38953.	10751034.	16968819.	4242205.	1927044.	23138068.
18	45328.	16197.	29611.	33259.	6125862.	237517.	40901.	11288585.	17817260.	4454315.	1927044.	24198619.
19	47594.	17006.	31092.	34922.	6432155.	249393.	42946.	11853015.	18708123.	4677031.	1927044.	25312198.
20	49974.	17857.	32646.	36668.	6753763.	261863.	45093.	12445665.	19643530.	4910882.	1927044.	26481456.

REQUIRED REVENUES

PRESENT VALUE OF INCOME STREAM	176206700.
AVERAGE/INITIAL ANNUAL REVENUE	16617631.
AVERAGE/INITIAL RFR	101.2206

ANNUAL CASH FLOW

YEAR	DIR OP COST	DEBT SRVC	TAXES	CAPITAL	CASH OUT	DEPREC	INTEREST	GR REVENUE	RFR	NET REVENUE	NPV-NT RV
1	7773612.	1927044.	2015236.	4730000.	13659295.	1188608.	1513600.	16617631.	101.	2958336.	2958336.
2	8162292.	1927044.	1797904.	0.	13927813.	1188608.	1480524.	16617631.	101.	2689818.	5448908.
3	8570407.	1927044.	1570182.	0.	14210234.	1188608.	1444803.	16617631.	101.	2407397.	7512863.
4	8998927.	1927044.	1331588.	0.	14507290.	1188608.	1406224.	16617631.	101.	2110341.	9188120.
5	9448874.	1927044.	1081619.	0.	14819755.	1188608.	1364558.	16617631.	101.	1797876.	10509612.
6	9921317.	1927044.	819753.	0.	15148443.	1188608.	1319559.	16617631.	101.	1469188.	11509517.
7	10417383.	1927044.	545440.	0.	15494213.	1108608.	1270960.	16617631.	101.	1123418.	12217461.
8	10938252.	1927044.	258113.	0.	15857972.	1188608.	1218474.	16617631.	101.	759659.	12660715.
9	11485165.	1927044.	-42826.	0.	16240674.	1188608.	1161788.	16617631.	101.	376957.	12864373.
10	12059423.	1927044.	-357995.	0.	16643328.	1188608.	1100568.	16617631.	101.	-25697.	12851519.
11	12662394.	1927044.	-688041.	0.	17066996.	1188608.	1034450.	16617631.	101.	-449364.	12643376.
12	13295514.	1927044.	-1033637.	0.	17512799.	1188608.	963042.	16617631.	101.	-895168.	12259454.
13	13960290.	1927044.	-1395485.	0.	17981921.	1188608.	885922.	16617631.	101.	-1364290.	11717675.
14	14658304.	1927044.	-1774315.	0.	18475609.	1188608.	802632.	16617631.	101.	-1857978.	11034501.
15	15391219.	1927044.	-2170886.	0.	18995182.	1188608.	712679.	16617631.	101.	-2377551.	10225037.
16	16160780.	1927044.	-2585991..	0.	19542028.	1188608.	615530.	16617631.	101.	-2924397.	9303146.
17	16968819.	1927044.	-3020453.	0.	20117615.	1188608.	510609.	16617631.	101.	-3499984.	8281534.
18	17817260.	1927044.	-3475126.	0.	20723493.	1188608.	397294.	16617631.	101.	-4105862.	7171847.
19	18708123.	1927044.	-3950902.	0.	21361296.	1188608.	274914.	16617631.	101.	-4743665.	5984749.
20	19643530.	1927044.	-4448704.	0.	22032752.	1188608.	142744.	16617631.	101.	-5415121.	4730000.