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ENERGY CONSERVATION

ENERGY USE IN THE MARINE TRANSPORTATION INDUSTRY

Task III—Efficiency Improvements
Task IV—Industry Future
Final Report, Volume IV

MASTER

December 1977

Work Performed Under Contract No. EY-76-C-03-1175

Booz, Allen and Hamilton, Incorporated
Bethesda, Maryland

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

U. S. DEPARTMENT OF ENERGY

Division of Transportation Energy Conservation

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FINAL REPORT - VOLUME IV
ENERGY USE IN THE MARINE TRANSPORTATION INDUSTRY:
TASK III - EFFICIENCY IMPROVEMENTS
TASK IV - INDUSTRY FUTURE,

for

Division of Transportation Energy Conservation
Non-Highway Transport Systems
U.S. Department of Energy
20 Massachusetts Avenue
Washington, D.C. 20545

December 1977

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I. INTRODUCTORY AND SUMMARY

This report covers the work accomplished under the third and fourth task of a four-task assignment which examines the energy use in the marine transportation industry. The work was performed for the Transportation Energy Conservation Division of the U.S. Department of Energy by Booz, Allen & Hamilton. The scope of the entire assignment is:

- Task I - Industry Summary - to define the current marine transportation industry in terms of population, activities and energy use
- Task II - Regulations and Tariffs - to define the regulatory structure surrounding the marine transportation sector and evaluate the energy use impact
- Task III - Efficiency Improvements - to identify conservation-related research and development programs and their costs and risks
- Task IV - Industry Future - to project a future industry scenario, evaluate the energy use implications and recommend specific courses of action to be pursued by the Department of Energy.

This assignment is one part of an overall program of the U.S. Department of Energy to develop baseline information and formulate strategies in the various transportation sectors.

1. OBJECTIVES OF THIS REPORT

The objective of this report, which encompasses Tasks III and IV, is to measure the characteristics of potential research and development programs that could be applied to the maritime industry. Once the energy use implications of the potential R&D programs are measured, recommendations for specific DOE courses of actions can be made.

To accomplish these objectives it was necessary to identify potential operating scenarios for the maritime industry in the year 2000, and determine the energy consumption that would result given those scenarios. This report does not purport to forecast the characteristics of the vessels or the trade flows that will constitute the marine transportation industry in the year 2000. It is only in the context of establishing an energy use point with which to evaluate the impacts of the potential R&D programs identified that it is necessary to develop future scenarios.

Future R&D concepts were identified that would potentially affect fuel savings if implemented across segments of the industry. The R&D programs are evaluated using the future scenarios to determine the relative energy savings potential associated with each.

2. SUMMARY OF RESULTS

In Volume II of "Energy Use in the Marine Transportation Industry," energy consumption in BTU's was established for the industry using a group of generic vessels to represent the U.S. and foreign flag fleets. In this fourth task, another group of generic vessels were postulated for the year 2000, as well as the level of trade that would be associated with that scenario. The overall industry scenario selected in this study is one of many possible futures and the aggregate energy consumption figures estimated for 1974 and 2000 are in no way dependent upon any one scenario or sector of the industry. The estimated energy consumption of the marine transportation industry for 1974 and 2000 is presented in Table I 1.

This study identified 15 specific program areas in four generic technology areas as shown in Table I-2. Programs in the area of marine fuels are discussed in a separate report entitled "Evaluation of the Alternatives for Contingency Fuels in the Commercial Marine Transportation Industry."

Each of the specific R&D programs was applied to the generic group of vessels associated with the scenarios for 1974 and 2000 as presented in Tables I-3 and I-4. The resultant energy and economic impacts associated with each R&D program were evaluated using the Marine Transportation Energy Model (MTEM) developed in Task I of the study. Table I-5 presents the results of the economic and energy impact analysis.

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

Industry Sector	1974 (estimate)			2000 (forecast)		
	Long Tons of Cargo Moved (millions)	Energy Consumed (quads)	%*	Long Tons of Cargo Moved (millions)	Energy Consumed (quads)	%*
Foreign trade						
U.S. flag	45.0	0.215	7	188.8	0.771	12
Foreign flag	609.9	2.145	73	1,384.8	4.821	72
Great Lakes	175.3	0.052	2	334.8	0.100	2
Inland waterways	535.8	0.089	3	704.5	0.100	2
Coastal	213.0	0.112	4	403.0	0.300	4
Offshore	-	0.064	2	-	0.200	3
Pleasure craft	-	0.225	8	-	0.300	4
Fishing and miscellaneous	-	0.032	1	-	0.100	2
Total	1,579.0	2.934	100.0	3,015.9	6.692	100.0

Source: Booz, Allen & Hamilton.
* Percentages may not add to 100 percent due to rounding.

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 (PIN)
Hydrodynamics	Submerged Air Cushions (SAC)
	Cutaway Hulls (CH)
	Tunnel Sterns (TS)
	Hull Maintenance & Smoothing (HMS)
Vessel Operations	Vessel Routing (VR)
	Plant Tuning (PT)

Source: Booz, Allen & Hamilton.

TABLE I-3
Application of Research and Development Programs to Generic U.S. Flag Vessels for the Year 1974

Industry Sector	Vessel Type	DWT	HP	Speed Knots (mph)	Main Propulsion Plants: HPTRS	SSD	DBC	AD	NAHBE	GTCC	CCGT	Propulsors: CR	PIN	Hydrodynamics: SAC	CH	TS	HMS	Vessel Operations: VR	PT
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							•	•										

Source: Booz, Allen & Hamilton.

TABLE I-4
Application of Research and Development Programs to Generic U.S. Flag Vessels for the Year 2000

							Program Areas														
							Main Propulsion Plants							Propulsors		Hydrodynamics				Vessel Operations	
Industry Sector	Vessel Type	DWT	H.P.	Speed Knots (mph)	Fuel Rate (lb/SHP-HR)	Deadweight Utilization Factor	HPTRS	SSD	DBC	AD	NAHBE	GTCC	CCGT	CR	PIN	SAC	CH	TS	HMS	VR	PT
Foreign Trade	Container	14,800	9,000	17.6	.37	.50			●										●	●	
	Container	20,000	24,000	22	.37	.50			●				●	●					●	●	
	Container	23,000	25,000	22	.37	.50			●				●	●					●	●	
	Container	28,000	40,000	25	.47	.50	●	●				●							●	●	●
	Ro/Ro	12,500	22,000	25	.37	.33			●			●	●	●					●	●	
	Ro/Ro	20,000	35,000	25	.47	.33	●	●				●	●	●					●	●	●
	Ro/Ro	22,000	36,000	25	.47	.33	●	●				●	●	●					●	●	●
	Barge	38,000	35,000	22	.47	.33	●	●				●	●	●					●	●	●
	Carriers	49,000	39,000	22	.47	.60	●	●				●	●	●					●	●	●
	Break Bulk	25,800	26,000	22	.37	.40			●				●	●					●	●	
	Tramp	11,760	7,000	15	.37	.40			●										●	●	
	Dry Bulk	30,000	10,000	15	.37	.96			●										●	●	
	Dry Bulk	45,000	12,000	15	.37	.96			●										●	●	
	Dry Bulk	60,000	13,500	15	.37	.96			●										●	●	
	Tankers	20,000	7,000	14	.37	.80			●										●	●	
	Tankers	40,000	9,000	14	.37	.80			●										●	●	
	Tankers	65,000	14,000	15	.37	.80			●										●	●	
	Tankers	150,000	20,000	15	.47	.80		●				●	●	●	●	●	●	●	●	●	●
	Tankers	300,000	36,000	15	.47	.80	●	●				●	●	●	●	●	●	●	●	●	●
Inland Rivers	Tug	12,061	2,171	(7.2)	.37	1.00			●	●	●										
Coastal	Tanker	44,000	12,500	(15)	.37	.80			●								●	●	●		
	Tug	13,000	2,250	(8)	.37	1.00			●	●	●										
	Other	16,500	22,000	(22.5)	.47	.33		●						●					●		
Great Lakes	Dry Bulk	30,000	10,000	(11)	.47	.96	●	●													
	Dry Bulk	30,000	10,000	(11)	.37	.96			●	●	●										
	Tug	11,000	3,000	(9)	.37	1.00			●	●	●										
Offshore	Tug				.37				●	●	●								●		
	Tug/Supply				.37				●	●	●								●		
	Supply				.37				●	●	●								●		
	Crewboat				.37				●	●	●								●		
Pleasure	None									●	●										
Fishing & Misc.	None				.37					○	●								●		

Source: Booz, Allen & Hamilton.

TABLE I-5
Results of Economic and Energy Impact Analysis

LEVEL OF TECHNOLOGICAL RISK	PROGRAM AREA	RANGE OF REDUCTION IN REQUIRED FREIGHT RATE (%) (1974)		ENERGY CONSERVATION POTENTIAL 1974 (% OF U.S. FLAG CONSUMPTION)	ENERGY CONSERVATION POTENTIAL 2000 (% U.S. FLAG CONSUMPTION)	POTENTIAL PROGRAM START	PROGRAM DURATION YEARS)	ESTIMATED FUNDING REQUIREMENTS TO LOWER RISK CATEGORY (MILLIONS OF $)		
		MINIMUM	MAXIMUM					LOW TO COMMERCIALIZATION	MEDIUM TO LOW	HIGH TO MEDIUM
LOW	SSD	1.0	8.2	5.5	12.7	FY-78	2	0.500	–	–
LOW	PT	0.2	1.4	1.4	0.0	FY-78	–	0.000	–	–
LOW	VR	0.0	0.0	0.0	0.0	FY-78	–	0.000	–	–
MEDIUM	DBC	2.1	5.2	3.6	11.2	FY-78	2	UNKNOWN	3.000	–
MEDIUM	HMS	0.0	3.3	3.1	6.2	FY-78	1	"	0.250	–
MEDIUM	GTCC	0.0	5.18	1.2	2.9	FY-78	2-3	"	4.000	–
MEDIUM	TS	0.2	1.0	0.6	0.9	FY-78	1	"	0.300	–
MEDIUM	CR	0.9	1.6	0.5	3.1	FY-78	2-3	"	4.000	–
MEDIUM	HPTRS	3.7	5.9	0.4	2.8	FY-78	10	"	3.000	–
MEDIUM	PIN	0.7	0.7	0.0	0.3	FY-78	2-3	"	1.000	–
MEDIUM	CH	0.6	0.6	0.0	1.4	FY-78	1	"	0.300	–
HIGH	ADI	0.0	0.0	10.2	6.7	FY-80	5	"	UNKNOWN	2.000
HIGH	NAF-BE	2.4	3.6	5.4	2.9	FY-79	3	"	"	1.000
HIGH	CCGT	5.2	7.4	1.4	2.7	FY-80	6-7	"	"	50.000
HIGH	SAC	1.5	1.6	0.0	0.7	FY-78	1	"	"	0.400

Source: Booz Allen & Hamilton.

3. ORGANIZATION OF THIS REPORT

This report consists of four chapters and five appendices. After this introductory chapter the operational, regulatory and vessel size scenarios for the year 2000 are developed in Chapter II. In Chapter III, future cargo flows and expected levels of energy use for the baseline 2000 projection are determined. In Chapter IV, the research and development programs are introduced into the future U.S. flag fleet and the energy savings potential associated with each is determined. The first four appendices (A through D) describe each of the generic technologies. The fifth appendix (E) contains the baseline operating and cost parameters against which the 15 program areas were evaluated.

II. THE INDUSTRY FUTURE, PROJECTED OPERATING, REGULATORY AND TECHNOLOGICAL SCENARIOS FOR THE YEAR 2000

The current levels of activity, regulatory scenarios and technology base that define the maritime transportation industry are described in Volumes II and III of this final report. The purpose of this chapter is to establish an energy use point or baseline for the year 2000 which will enable the potential research and development programs identified in Chapter IV to be evaluated.

The projected technology base for the year 2000 will be limited to expected growth in vessel sizes and changes in shipping technology. The research and development programs identified in Chapter IV will then be evaluated against this baseline. The expected scenarios for each of the seven industry segments[1] are described in the following sections.

1. THE FOREIGN TRADE SECTOR

The oceangoing merchant fleet serving U.S. foreign trade is defined as those steel-hulled, self-propelled vessels over 1,000 gross registered tons capable of operating in the U.S. - foreign trade. There are five primary types of service offered by the foreign trade sector:

- Liner
- Nonliner or tramp
- Dry bulk
- Tanker
- Passenger.

Each is discussed below.

(1) Liner Vessels

Liner vessels operate as common carriers and provide a regularly scheduled service between specified ports. This portion of the ocean shipping sector is characterized by fast ships moving relatively high value cargo.

1 . Developed in Volume II, "Energy Use in the Marine Transport Industry - Industry Summary."

1. Growth of Intermodalism

There are a variety of vessel types employed in liner service that differ primarily in their method of cargo handling. Liner vessels have been classified according to ship type in the following four categories:

- Break-bulk and partial container
- Container
- Roll-on/Roll-off (Ro/Ro)
- Barge carriers.

This variety has resulted from the growth of various types of intermodal transportation systems. The intermodal vessels call on fewer ports and minimize their port time due to more efficient cargo handling techniques and links to other transportation modes.

The increasing trend towards intermodalism in international shipments that has been evident over the past 15 years is expected to continue. Container vessels were the first intermodal concept and first introduced by Sea-Land Services, Inc. in the domestic coastwise trade during the 1950's. The growth of the intermodalism is shown by the fact that by 1974, 43 percent[2] of all U.S. liner cargo was being carried in containers. Other intermodal vessels are also gathering an increasing share of the world's liner market.

This growth of intermodalism is expected to continue. For the purposes of this analysis, the distribution of liner cargo by vessel type and essential trade route is shown in Table II-1.

2. Growth in Vessel Size

A recent MarAd-sponsored study[3] has projected liner vessels to grow, as shown in Table II-2.

---

2 "Containerized Cargo Statistics, Calendar Year 1974," Department of Commerce, Maritime Administration.

3 "A study of the Future Requirements for Ships That Will Be Engaged in the U.S. World Trade for Both the Short and Long Term," Temple, Barker and Sloane, Inc., for the Office of Maritime Technology, U.S. Maritime Administration, 1977.

TABLE II-1
Distribution of Liner Cargo by Vessel Type - 2000

Essential U.S. Trade Routes	Percent Distribution by Vessel Type			
	Container Vessel	Ro/Ro	Barge Carrier	Break-bulk and Partial Container
1	25		25	50
2	25		25	50
4	40	40		20
5-7-8-9	90	9		1
6	90			10
10	40	20		40
11	95			5
12	60			40
13	40	20		40
14	20			80
15A	20			80
15B	20			80
16	80			20
17			40	60
18		40	40	20
19	20	20	30	30
20	25		25	50
21	80			20
22	30		30	40
23	20	20		60
24	25		25	50
25	25		25	50
26	90			10
27	80		10	10
28	20	30	30	20
29	80	10		10
31	25		25	50

Source: Booz, Allen & Hamilton.

TABLE II-2
Growth (Reduction) in Liner Vessel Parameters 1975 - 2000

Vessel Type	Percent Increase in DWT/Ship	Percent Increase in Horsepower	Percent Increase in Speed
Break-bulk	91	74	16
Containerships	23	30	10
Barge carriers	17	(6)	(1)
Ro/Ro	not addressed		

Source: See Footnote 3.

Based on these projections, generic[4] liner vessels for the year 2000 were defined, as shown in Table II-3. The procedure used to develop Table II-3 utilized the percentage increase in DWT and speed as calculated in the MarAd study and shown in Table II-2. The horsepower levels required by that deadweight and speed were taken from Figure II-1.

3. U.S. Flag Share

U.S. flag liner vessels are expected to benefit from flag preference legislation.

This flag preference scenario assumes that the trend of national flag preference actions on the part of individual countries working through bilateral trade agreements or countries working through international forums such as the United Nations, will continue. The proposed United Nations code of conduct for liner conferences (UNCTAD) would reserve cargo on a 40-40-20 basis, with 40 percent of all cargo reserved for the fleets of the two trading partners and 20 percent for ships flying a third flag. This cargo sharing formula has been under consideration by United Nations members for the past few years. Although still far from being accepted, the UNCTAD code is illustrative of the trend towards national flag preference for liner trades that is already a reality in the bulk trades.

Between 1965 and 1972, the U.S. flag participation in all liner movements was quite constant and varied between 22 and 24 percent. Starting in 1973, the U.S. flag share grew to 26 percent and then to 30 percent in 1974 and 1975. This increase in U.S. flag share was due to a complex interrelationship between four factors:

- The tendency of U.S. operators to employ more productive liner vessels than their foreign counterparts.

- The increased effectiveness of MarAd's market development organization in assisting the U.S. flag operators to secure both commercial and government-sponsored cargo.

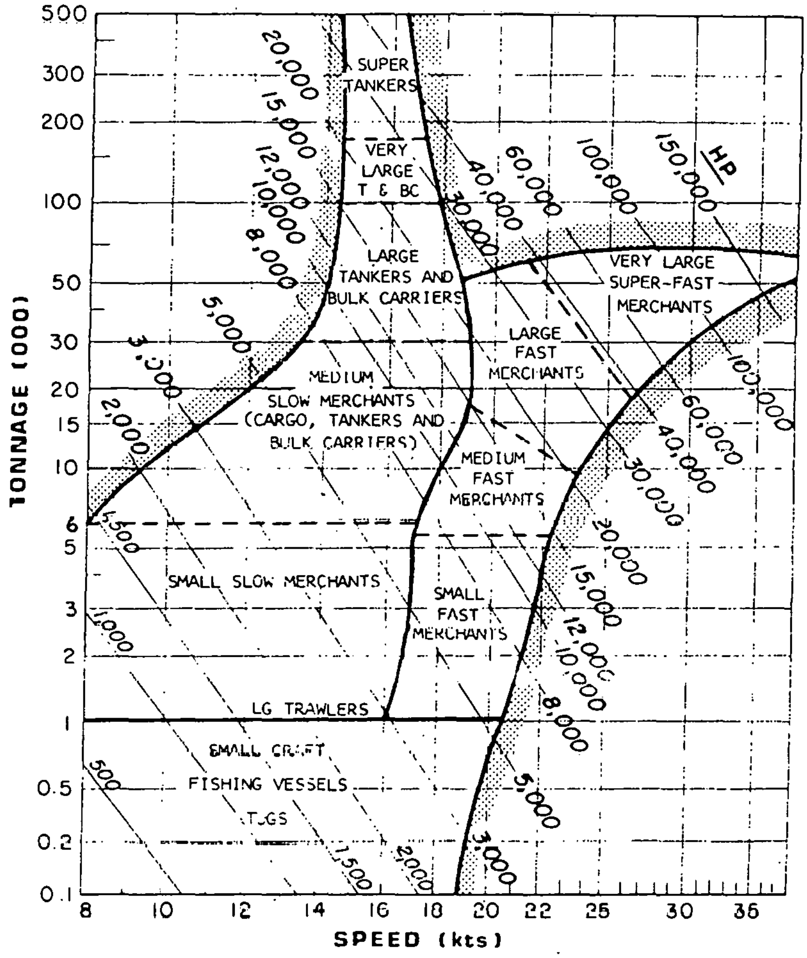
---

4 Generic vessels are representative of the typical vessel type found in a particular industry sector.

TABLE II-3
Changes in Generic Liner Vessels
1974 to 2000

Liner Vessel Type	Year	Deadweight (long tons)	Horsepower	Speed (knots)	Fuel Rate (lb/SHP-hr)	Deadweight Utilization Factor (percent)
Break-bulk	1974	13,500	14,500	19.0	.47	40
	2000	25,800	26,000	22.0	.37	40
Containership	1974	12,000	8,000	16.0	.47	50
	2000	14,800	9,000	17.6	.37	50
	1974	16,500	17,000	20.0	.47	50
	2000	20,000	24,000	22.0	.37	50
	1974	18,500	18,000	20.0	.47	50
	2000	23,000	25,000	22.0	.37	50
	1974	23,000	28,000	23.0	.47	50
	2000	28,000	40,000	25.0	.37	50
Ro/Ro	1974	10,000	11,000	24.0	.47	33
	2000	12,500	22,000	25.0	.37	33
	1974	16,500	22,000	22.5	.47	33
	2000	20,000	35,000	25.0	.37	33
	1974	18,000	25,000	22.5	.47	33
	2000	22,000	36,000	25.0	.37	33
Barge carriers	1974	33,000	33,000	22.0	.47	60
	2000	38,000	35,000	22.0	.37	60
	1974	42,000	38,000	22.0	.47	60
	2000	49,000	39,000	22.0	.37	60

Source: Bocz, Allen & Hamilton.



Source: "Trends in Merchant Shipping," Donald Ross, Tetratech Report to Naval Undersea Center.

FIGURE II-1
Operating Diagram for Major Ship Types

- The leadership of several U.S. flag companies in the area of innovative liner services such as minibridge.

- Certain traditional liner cargoes have shifted to the nonliner segment. It is believed that many of these lower rated cargoes impacted the foreign flag liner segments more than the U.S. flag sector, thus causing a relative increase in U.S. flag liner share.

For the purpose of this analysis, it is expected that the U.S. maritime community will continue to maintain its technological lead through the year 2000, and together with increased worldwide emphasis on national flag cargo preference, the U.S. flag share of liner movements will rise to 40 percent.

(2) Passenger Vessels

Cruise volume projections have been based on past U.S. Army Corps of Engineer passenger statistics. Table II-4 presents recent passenger statistics at the five major east coast cruise ports for the 1965 through 1974 period.

TABLE II-4
Number of Passengers Passing Through
Major Cruise Ports
(in thousands)

Year	Major Cruise Ports					
	New York	Baltimore	Charleston	Port Everglades	Miami	Total
1965	893	14	453	336	535	2,231
1966	822	13	535	345	495	2,210
1967	725	9	576	433	345	2,088
1968	631	10	514	483	454	2,092
1969	663	3	391	527	707	2,291
1970	573	176	261	459	608	2,077
1971	567	98	255	571	695	2,186
1972	1,075	128	263	557	710	2,733
1973	1,154	183	258	356	759	2,710
1974	405	177	234	323	569	1,708

Source: "Waterborne Commerce of the United States," 1974, U.S. Army Corps of Engineers.

As can be seen, the total number of passengers passing through all east coast ports fell from a level of 2.23 million in 1965 to a low of 2.09 million in 1967 and then increased from 1967 through 1973. 1974 saw a 37 percent drop from the high set in 1973. Growth rates over selected periods are:

- 1965 to 1974 - average of -3 percent per annum
- 1965 to 1973 - average of 2.5 percent per annum
- 1967 to 1973 - average of 4.4 percent per annum.

Due to the great variations in growth rates over the recent past, selection of a growth rate for cruise activity is extremely difficult. The decline and cessation of regularly scheduled passenger traffic on the transatlantic trade is taken into account, as well as the growth of the cruise industry in the U.S. South Atlantic and gulf area. Coupled with an anticipated higher growth rate for air fare versus cruise fares, due to the higher energy intensiveness of air travel, a 2 percent annual growth of cruise travel is projected for the 1974-2000 period. All cruise traffic is expected to be foreign flag service.

(3) Nonliner or Tramp Vessels

Tramp vessels, in contrast to liner vessels, offer irregular service and are available for hire to a shipper under either a time or voyage charter, to load and discharge specified cargo between such ports as the charter stipulates. In some cases, foreign flag operators move their vessels between liner and tramp service. Another perturbation occurs when an operator offers berth service in one direction on a trade route and tramp service in the other direction. A typical tramp vessel is generally of the break-bulk variety, but is different in that it is a generally older and slower vessel with a smaller cargo carrying capacity than a break-bulk liner vessel.

1. Growth in Tramp Vessel Size

Tramp vessels are typically chartered to transport small lots of traditional bulk commodities such as grains or sugar and low value neobulk commodities such as:

- Animal feed
- Wood (primary and rough)
- Wood pulp and wastepaper
- Scrap
- Iron and steel products.

The previously cited MarAd report (see page II-2) projected a growth in the typical neobulk carrier between 1974 and 2000 of:

- 40 percent in deadweight
- 41 percent in horsepower
- 8 percent in speed.

Based on these projected growth rates, the deadweight of the generic tramp vessel was increased 40 percent and the speed increased 8 percent. Power levels were taken from Figure II-1. A comparison of the generic tramp vessel in 1974, with that postulated to be in service during the 2000 time frame, is shown in Table II-5.

TABLE II-5
Changes in Generic Tramp Vessel
1974 - 2000

Year	Deadweight (long tons)	Horsepower	Speed (knots)	Fuel Rate (lb/SHP-hr)	Deadweight Utilization Factor
1974	8,400	5,000	14	.37	40%
2000	11,760	7,000	15	.37	40%

Source: Booz, Allen & Hamilton.

2. U.S. Flag Share

For the purpose of this analysis, no major regulatory changes are anticipated in the tramp sector, and U.S. flag share of the tramp trades is expected to remain at the current level of 4 percent.

(4) Dry Bulk Vessels

Dry bulk carriers are designed to carry such bulk cargoes as grains and ores. This group also includes ore/bulk/oil (OBO) vessels suited for both the liquid and dry bulk trades. Like tramp vessels, dry bulk carriers are chartered on a time or voyage basis, and are drawn from the world pool.

Dry bulk carriers are engaged in importing such commodities as sugars, fertilizers, iron ore, and exporting such commodities as grain, coal, and fertilizers in the United States' foreign trade. Dry bulk shipments primarily originate or terminate on the east and gulf coasts. These vessels typically call at one or two ports on each leg of the voyage and rarely spend more than one or two days in port. The typical operating profile of a dry bulk carrier is loaded in one direction and return in ballast. There is generally little opportunity for backhaul cargo.

1. Growth in Dry Bulk Vessel Size

The previously cited MarAd report (see page II-2) projects a growth in the average dry bulk vessel of:

- 49 percent in deadweight
- 42 percent in horsepower
- 3 percent in speed.

Based on these projected growth rates for deadweight, speed and power levels from Figure II-1, the generic dry bulk carriers were changed, as shown in Table II-6, on the following page.

2. U.S. Flag Share

The dry bulk trades are expected to show increased U.S. flag participation due to:

- Increased national awareness of the national security implications of continued reliance on foreign flag vessels to carry over 95 percent of our dry bulk trades

TABLE II-6
Changes in Generic Dry Bulk Vessels
1974 - 2000

Year	Deadweight (long tons)	Horsepower	Speed (knots)	Fuel Rate (lb/SHP-hr)	Deadweight Utilization Factor
1974	20,000	8,000	15	.37	96%
2000	30,000	10,000	15	.37	96%
1974	30,000	10,000	15	.37	96%
2000	45,000	12,000	15	.37	96%
1974	40,000	11,000	15	.37	96%
2000	60,000	13,500	15	.37	96%

Source: Booz, Allen & Hamilton.

- Increased government sponsorship of U.S. flag dry bulk shipping programs.

The recurring interest shown in cargo preference legislation for petroleum imports is expected to benefit the U.S. dry bulk fleet. For the purposes of this analysis, it is assumed that by the year 2000, 10 percent of our dry bulk trade will be carried by U.S. flag vessels.

(5) Tank Vessels

Tankers are designed for the carriage of liquid bulk cargoes such as crude oil, refined petroleum products, chemicals and edible oils. These vessels are also used to move dry bulk cargoes that can be handled using pumping or suction systems. They have been employed extensively in the U.S. foreign grain trade.

Crude petroleum destined for the United States generally originates in South America, Africa, and the Arabian Gulf, while clean petroleum products move primarily from the Caribbean area to the U.S. east coast.

As with dry bulk carriers, tankers typically call at only one port on each leg of the voyage, spend a minimum amount of time in port, and carry no backhaul cargo.

1. Growth in Tank Vessel Size

One major technological advance is expected in the U.S. - foreign tanker trade by the year 2000. Deepwater ports, such as LOOP, currently proposed for the gulf coast are expected to be operating on all three coasts by the year 2000. The State of Washington has sufficient water depth in Puget Sound to handle the largest tankers currently in existence. Exxon is currently constructing a single point mooring buoy for the Santa Barbara channel that will be located in 440 feet of water.

Based on this expected growth in vessel size, the tankers involved in the importation of crude oil will grow to the maximum size available. Those tankers involved in the exportation of chemical and petroleum products are expected to remain at approximately the same size, however, they will become increasingly more specialized. The expected change in generic tank vessels is shown in Table II-7.

TABLE II-7
Changes in Generic Tank Vessels
1974 - 2000

Year	Deadweight (long tons)	Horsepower	Speed (knots)	Fuel Rate (lb/SHP-hr)	Deadweight Utilization Factor
1974	20,000	7,000	14	.37	96%
2000	same	-	-	-	80%
1974	40,000	9,000	14	.37	96%
2000	same	-	-	-	80%
1974	65,000	14,000	15	.37	96%
2000	same	-	-	-	80%
1974	80,000	16,000	15	.37	96%
2000	150,000	20,000	15	.37	80%
1974	150,000	20,000	15	.37	96%
2000	300,000	36,000	15	.37	80%

Source: Booz, Allen & Hamilton.

2. Expected Environmental Impacts

Due to a series of 15 major incidents involving oil tankers off the U.S. coast or in U.S. harbors, between December 15, 1976 and March 27, 1977, the United States Congress and the U.S. Coast Guard have under consideration a regulation that would require all tankers entering U.S. waters to be fitted with segregated ballast. A requirement to dedicate a certain percentage of the available cargo tank space of a tanker to ballast service only, impacts the energy efficiency (BTU's/ton-mile) and will reduce the deadweight utilization of tankers from approximately 96 percent to 80 percent by the year 2000.

It is expected that new hull forms will be developed over the next few years, such as the cut-away hull form now under investigation by the Gulf Oil Corporation, that will reduce the penalty associated with segregated ballast requirements. These research and development options are discussed in greater detail in Appendix C.

3. U.S. Flag Share

The Administration recently gave its approval to cargo preference legislation reserving 9.5 percent of all petroleum imports for U.S. flag tankers. This measure ultimately failed to pass in Congress. But, the recurring interest shown in cargo preference legislation for petroleum imports is expected to increase U.S. flag share over time. For the purposes of this analysis, U.S. flag share in the year 2000 was taken as 10 percent of the total tanker trade.

2. THE GREAT LAKES SECTOR

The Great Lakes sector of the U.S. merchant fleet has been defined as those vessels operating within the Great Lakes/St. Lawrence Seaway system. The system stretches for more than 2,300 miles from the Atlantic Ocean to mid-America, with a controlling depth of 27 feet. There are 16 locking points and more than 155 miles of channels and canals in the system. Traditionally, the Great Lakes operating season has been cut short by the winter season, as icing on the lakes has rendered navigation virtually impossible. In recent years, successful attempts have been made in extending the operating season in certain sections from 10 to 12 months.

Waterborne commerce in the Great Lakes can be divided into the following categories:

- Domestic interlake and intralake movements or trade between U.S. ports within a specific lake or between lakes

- Trans-lakes movements between the United States and Canada

- Overseas foreign movements.

In 1974, the distribution of the tonnage involved in these categories is shown in Table II-8.

TABLE II-8
Great Lakes Trade During 1974

Service	Total Trade in Millions of Long Tons	Percent
Domestic	138.2	75
Trans-lake	37.7	20
Overseas foreign	8.1	5
Total	184.0	100%

Source: "Domestic Waterborne Trade of the United States 1967-1974," Maritime Administration U.S. Department of Commerce.

(1) <u>Growth in Great Lakes Vessels</u>

The growth in size of vessels involved in the domestic and trans-lake Great Lakes trade categories by the year 2000 is expected to be as dramatic as that expected in the foreign trade sector, but will be guided by a number of constraining factors:

- Size limitations imposed by existing lock and channel width and draft constraints

- Size limitations imposed by loading facilities
- Liquid bulk storage capacities
- Extremely long life spans for Great Lakes vessels.

The last point is quite important. Approximately 70 percent of the current U.S. Great Lakes fleet is over 30 years old. Some existing vessels date to 1897. With an expected life span of 40 to 50 years, the average size of Great Lakes bulk freighters based on the total number of active vessels is expected to change slowly. For the purposes of this analysis the size of Great Lakes bulk freighters increases substantially in the year 2000 to reflect the dominance of the newer, larger vessels in terms of percent of tonnage moved. Currently, the older vessels in the Canadian and U.S. dry bulk fleets are slowly being replaced. The vessels being replaced are the older, coal fired reciprocating steam engined vessels. As of December 1975, there were 11 Great Lakes bulk carriers on order ranging in size from 6,700 DWT to 59,000 DWT, as shown in Table II-9.

Table II-9 underscores the trend towards larger vessels and the limiting factor of the locks and entrance channels. Currently, the vessel size limit at the "Soo" Locks is 1,000-foot length overall, by 105-foot beam.

TABLE II-9
Great Lakes Dry Bulk Carriers on Order
December 1975

Shipyard	DWT	Overall Length	Horsepower	Delivery
American Ship Building	59,000	1,000'	16,000	1976
American Ship Building	59,000	1,000'	16,000	1977
American Ship Building	59,000	1,000'	16,000	1978
Port Weller Dry Docks	33,000	730'	10,000	1976
Bay Shipbuilding	42,400	770'	10,500	1976
Collingswood Shipyards	31,250	730'	unknown	1976
Collingswood Shipyards	6,700	355'	4,000	1976
Bay Shipbuilding	36,000	728'	7,000	1976
Bay Shipbuilding	unknown	1,000'	unknown	1977
Bay Shipbuilding	unknown	1,000'	unknown	1978
Bay Shipbuilding	unknown	730'	unknown	1976

Source: "Greenwood's Guide to Great Lakes Shipping," 1975.

Based on the projected increases in shipments of iron ore, coal, and other mining products, and the current trends in new buildings, it is expected that the average size of the domestic Great Lakes dry bulk carrier will increase to 30,000 DWT by the year 2000.

At all other locks in the Great Lakes-St. Lawrence Seaway System, the maximum size limit is shown in Table II-10.

TABLE II-10
Maximum Dimensions for Vessels Transiting the St. Lawrence Seaway

Length	-	730 feet
Beam	-	75 feet, 6 inches
Draft	-	25 feet, 9 inches (fresh water)

Source: St. Lawrence Seaway Development Corp.

These dimensions effectively limit the maximum size of vessels able to serve the Great Lakes to approximately:

- General cargo vessels - 14,000 DWT
- Bulk carriers - 25,000 DWT

As a result the ships in the Great Lakes overseas service are expected to grow at a much lower rate than the domestic trades.

(2) Expected Regulatory Impacts

Increased environmental concerns and the establishment of a zero discharge criteria on the Great Lakes is expected to eliminate almost all tanker traffic.

It is expected that by the year 2000, the majority of the petroleum distribution occurring on the Great Lakes will be done by barge, with very little carried by self-propelled tanker. The current U.S. flag tanker fleet consists of 15 vessels with a capacity greater than 10,000 bbls. Of these only three have been built since 1950. The U.S. tank barge fleet consists of 47 units of which 40 have been constructed since 1950. The total capacity of the barge fleet is approximately three times that of the self-propelled fleet. In addition, the Great Lakes tanker fleet will also be subjected to segregated ballast requirements that will make barging operations more attractive. Based on these expected scenarios, all forecasted petroleum distribution was allocated to tug/barge operations.

The generic tug/barge was estimated to increase in size by 120 percent, which is the same percentage increase that was forecasted for the growth in marine tonnage, as discussed in Chapter III.

The expected changes in the generic vessels on the Great Lakes is shown in Table II-11.

TABLE II-11
Changes in Generic Great Lakes Vessels
1974-2000

Vessel Type	Year	Deadweight (long tons)	Horsepower	Speed (mph)	Fuel Rate (lb/SHP-HR)	Deadweight Utilization Factor
Dry Bulk Carrier	1974	15,000	4,000	11	.37 to .50	.96
	2000	30,000	10,000	11	.37	.96
Tanker	1974	4,000	1,500	11	.37 to .47	.96
	2000	none				
Tug	1974	5,143	900	11	.37	.96
	2000	11,000	3,000	11	.37	.96

Source: Booz, Allen & Hamilton.

3. THE COASTAL SHIPPING FACTOR

The coastal shipping sector of the U.S. merchant fleet was defined as those vessels transporting cargo in the U.S. domestic deep-sea trade, which is protected from foreign competition by the Jones Act. This sector includes the non-contiguous trades with Puerto Rico, Hawaii, and Alaska.

Nearly all of the cargo movements in the domestic deep-sea trade consist of bulk commodities transported by either tanker or barge. In 1974, nearly 213 million long tons of cargo was carried in this trade, 90 percent of which was bulk commodities. Movements of non-bulk commodities are handled predominantly by coastwise container feederships and Ro/Ro ships. The coastal fleet was divided into the following three categories:

- Tanker
- Tug/barge
- Other coastal.

(1) Growth in Vessel Size

Growth in the size of the three generic vessel types involved in the coastwise trade will be constrained by:

- Tankers — coastal petroleum trade is predominately distribution of fuel and other refined products (approximately 87 percent). Size is restricted by available water depth and storage capacity at discharge points.

- Tug/barge — coastal trade is predominately petroleum products and dry bulk commodities. Storage capacity at discharge points will constrain growth.

- Other coastal — the size of coastal feeder vessels are expected to be constrained only by the growth of the market.

The prime inhibitors of growth in size for the tanker and tug/barge are physical limitations of the current harbors. For this reason, a modest growth in size of 10 percent is projected for these two generic vessel types for the year 2000. Cargo forecasts for the coastal feeder services are based on an expected developing market. The vessels most likely to be deployed in a feeder service will most likely be older liner vessels that are currently employed in the foreign trade sector. Table II-12 gives the expected changes in the generic coastal vessels for the year 2000.

TABLE II-12
Changes in Generic Coastal Vessels
1974 - 2000

Vessel Type	Year	Deadweight (long tons)	Horsepower	Speed (knots)	Fuel Rate (lb/SHP-hr	Deadweight Utilization Factor
Tanker	1974	40,000	12,000	16	.47	.96
	2000	44,000	12,500	15	.37	.80
Tug/ Barge	1974	11,430	2,000	8	.37	-
	2000	13,000	2,250	8	.37	-
Other	1974	7,800	6,000	15.5	.47	.50
	2000	16,500	22,000	22.5	.47	.33

Source: Booz, Allen & Hamilton.

(2) Operational and Regulatory Changes

Expected changes in the existing operational practices and regulatory constraints are:

- As line vessels get larger and faster, there exists a need to minimize the nonproductive port time that a large container vessel spends on each round trip. The easiest way to accomplish this is to eliminate all but one port call on each leg of the voyage and utilize a feeder system to distribute cargo to outlying ports. These systems currently exist throughout Europe and have been introduced to the U.S. coastwise trade by Sea-Land Services, Inc. using self-propelled vessels and Seatrain Lines, Inc. and McAllister Brothers, Inc. using tug/barge systems. The growth of these systems is expected to continue. Table II-13 presents an energy comparison of a North Atlantic trade feeder system with the more traditional direct call service.

- Increased environmental concerns will extend the segregated ballast requirement for tankers discussed under the foreign trade shipping sector to tankers in the coastal shipping trades resulting in a decrease in their deadweight utilization factor from .96 to .80.

4. THE OFFSHORE SECTOR

The offshore sector is expected to show the most dramatic technological changes of all of the marine transportation sectors. New activities, such as:

- Offshore thermal energy conversion (OTEC)
- Deep ocean mining

are anticipated by the year 2000, plus increased activity in offshore oil exploration.

TABLE II-13
Energy Impact of Sample North Atlantic Feeder System[5]

Type of Service	One-Way Mileage	Round Trips/Year Line Haul	Tons Fuel Per Trip	BTU's/Trip X 10^9
Feeder System				
Line haul[6]	3,387	52	1,732	71.80
Domestic[7]	1,360	-	170	7.34
				79.14
Direct Call				
Line haul	3,387	39	1,732	71.80
Portion Off-Route	783	-	426	17.66
				89.46
Energy savings with feeder system				10.32 or 11.5%

Current activities in the offshore sector were categorized in Volume II[8] as:

- Exploration
- Drilling and production
- Service and supply
- Pipelaying and construction.

The expected new activities of offshore thermal energy conversion and deep ocean mining will place additional demands on the service and supply and construction categories. Increased activity in the offshore oil exploration is expected to require more semisubmersible drilling rigs and dynamically positioned drillships as the search for oil moves further offshore. Supply craft are expected to increase in size and the number required to service a drilling rig is expected

5 Line haul between New York and Rotterdam, outports are Boston, Philadelphia and Baltimore.

6 Containership with speed of 22 knots, consumes 134 tons/day at sea and 17 tons/day in port, residual fuel.

7 Tug/barge with speed of 8 knots, consumes 11.2 tons/day at sea and 6.3 tons/day in port, diesel fuel.

8 Volume II, "Energy Use in the Marine Transport Industry - Industry Summary."

to increase as the distances from supply bases increases. Table II-14 gives the expected changes in the generic offshore vessel types for the year 2000.

TABLE II-14
Changes in Offshore Generic Vessels
1974 - 2000

Activity	Vessel Type	Year	Length (water depth)	Horse-Power	Fuel Rate (lb/SHP-hr)	Level of Activity 2000
Drilling	Submersible	1974 2000	(80') none	- -	50 bbl/day -	1974=174 rig years projected increase of 2.5%/year; 331 rig years by 2000
	Drillship & barges	1974 2000	(20,000') (30,000')	- -	100 bbl/day -	
	Jack-up's	1974 2000	(600') (600')	- -	100 bbl/day -	
	Semisubmersible & tension leg	1974 2000	(6,000') (10,000')	- -	100 bbl/day 100 bbl/day	
Logistics	Crewboats	1974 2000	90' 100'	1800 2000	.37 .37	3 boats per rig year
	Tug	1974 2000	100' 150'	4000 7200	.37 .37	
	Tug/supply	1974 2000	190' 200'	3300 8000	.37 .37	
	Supply	1974 2000	170' 200'	3300 7000	.37 .37	
Other	Mining vessels	1974 2000	none 700'	- 7000	- .37	
	Offshore construction and thermal energy conversion					See Note

Note: Energy consumption is equivalent to 30% of logistic activity.
Source: Booz, Allen & Hamilton.

5. THE INLAND WATERWAYS SECTOR

The inland waterways sector of the U.S. Merchant Marine is defined as those vessels operating between ports in the United States where the movement takes place entirely in rivers, canals, ports, channels, and other inland waters. Vessels operating within the U.S. Great Lakes system were discussed previously.

Most of the vessels operating upon the U.S. inland waterway system fall into the following categories:

- Towboats
- Tugboats
- Barges.

The towboat is a virtually flat-bottomed vessel which serves as the power unit for "push-towing" barges, in waterways that are protected or relatively calm in their natural state. Barges are lashed together by cables and ropes to form a single unit for push-towing. The towboat pushing from the rear of the tow is capable of handling a greater number of barges under better control than in the "pull-towing" method. These diesel powered vessels are capable of pushing barges carrying as much as 50,000 tons of cargo. The use of multiple rudders and Kort[9] nozzles allows maximum control in forward, backing, and flanking movements; all necessary to navigate the winding channels of the inland rivers and canals.

Over the past 40 years, the productivity of the inland towing industry has increased tremendously. The output of a typical barge tow has risen from 150,000 ton-miles per day to over 3 million and the average length of haul has increased from 50 to 375 miles. Large tows on the lower Mississippi are now on the order of 50,000 tons with towboats reaching 10,500 horsepower and the amount of cargo moved on the inland waterways of the United States has more than tripled since the 1930's.

This rate of growth is expected to slow dramatically over the next 20 years. Increasing environmental pressures and competitive railroad lobbying are currently stalling major public works projects such as the upgrading of Lock and Dam 26 on the Mississippi River and the Tennessee-Tombigbee project.

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9 A Kort nozzle is a funnel-shaped structure built around the propeller to concentrate the flow of water and thereby increase the thrust and efficiency of the propeller.

The capacity of the inland river system is expected to grow slowly. Major changes in the current operating constraints, such as maximum lock sizes of 1200 feet x 110 feet and minimum project depth of 9 feet are not expected.

Inland waterway user charges will become a reality by the year 2000. Impacts could result in a shift of up to 10 percent of the total ton-miles carried on the system to competing modes. However, it is felt that current barge rates have served to restrain the rise of competing rail rates. An inland waterway user charge will force a rise in barge rates which will be matched by a corresponding rise in competing rail rates. The overall impact of inland waterway user charges will, in all probability, be well within the range of error associated with cargo movement forecasts for the year 2000.

The current average tow, representing all cargo movements on the inland river systems was defined[10] as:

- 1,350 horsepower towboat
- 7,714 tons of cargo
- 358 miles average haul.

Based on the expected slowdown in the growth of productivity on the inland rivers, the growth rates, shown in Table II-15, were used to project the average tow for the year 2000.

TABLE II-15
Expected Growth Rates for the Inland Rivers

Parameter	Parameter Value 1974 to 1976	Recent Historical Growth Rate Per Annum	Growth Rate 1974 - 2000 Per Annum	Parameter Value 2000
Average towboat	1,350 HP	2.9 %	2.00%	2,171 HP
Required HP/ton	.175 HP/ton	unknown	0.0%	0.175 HP/ton
Average haul distance	358 miles	0.83%	0.42%	396 miles

Source: Booz, Allen & Hamilton.

10 Average Horsepower and haul mileage was extracted from U.S. Army Corps of Engineers data, average cargo haul in tons was calculated using an average of 0.175 required horsepower per ton.

6. THE FISHING AND MISCELLANEOUS SECTOR

The U.S. commercial fishing fleet can be characterized as fragmented and dominated by single family, one boat operations. According to the National Marine Fisheries Service, the U.S. fishing fleet consists of over 15,000 vessels with capacities in excess of 5 net tons and more than 72,000 boats with capacities less than 5 net tons. The U.S. Coast Guard listing of fishing craft includes approximately 22,000 craft. Many fishing craft are registered with municipal or state agencies, and most small craft are not required to register at all. In 1973, the U.S. fishing fleet landed a catch of nearly 5 billion pounds of seafood.

According to the U.S. Coast Guard, there are approximately 300 miscellaneous or harbor service craft registered with that organization. This classification includes such craft as fireboats, ice breakers, pilot boats, police and patrol boats. Miscellaneous service craft were judged to be insignificant in determining energy consumption because these vessels are generally small in size and see limited duty in local harbor areas.

An examination of that portion of the U.S. fishing fleet that is registered with the U.S. Coast Guard, as shown in Table II-16, resulted in the following average characteristics:

- Average engine size - 224 horsepower
- Average age - 22.6 years.

TABLE II-16
Age Distribution of the U.S. Fishing Fleet

Horsepower Range	0 to 50	51 to 100	101 to 500	501 to 1000	1001 to 5000	5001 to 10,000
No. of vessels	695	3,402	17,424	677	237	2
Average horsepower	35	82	215	679	2,100	5,875
Average age	37.7	33.0	20.4	15.8	14.4	3.0
Percent age 0-19 years	13	17	53	64	69	100
Percent age 19-39 years	41	52	35	31	30	0
Percent age over 40	46	31	12	5	1	0

Source: U.S. Coast Guard, Vessel Registry File.

The analysis shown in Table II-16 underscores the fact that the U.S. fishing fleet is composed of older, smaller vessels with vessels 19 years or older dominating the over 100 horsepower class. Caution must be exercised, however, as the U.S. Coast Guard vessel file contains approximately half the fishing vessels estimated by the National Fisheries Service, U.S. Department of Commerce.

Expected technological changes in the character of the fleet will be driven by the extension by the United States of its territorial claims to fishing privileges from 12 to 200 miles. Expected changes will include:

- Scrapping of the older, smaller vessels that are unable to work and maintain station out to 200 miles
- Replacement of the older vessels with larger vessels, capable of maintaining station for months and equipped with processing plants and refrigerated cargo holds.

It is expected that these projected changes will increase the amount of energy consumed by the U.S. fishing fleet.

7. THE RECREATIONAL BOATING SECTOR

This sector consists of those small craft used exclusively for recreational purposes. The U.S. Coast Guard estimated that there were over 9 million recreational boats owned by Americans in 1975. Of these, more than 7 million were motor-powered boats.

Recreational boating statistics were subdivided into the following types of motorized boats:

- Canoe
- Houseboat
- Inboard
- Inboard/outboard
- Outboard
- Rowboat/jonboat
- Sailboat
- Other.

The latest comprehensive recreational boating survey[11] performed by the U.S. Coast Guard in 1973, identifies powerboats by type and region of the country.

Volume II of this study[12], an analysis of the operational parameters of the recreational sectors contained in the latest Coast Guard survey of recreational boating, indicated that the average motor driven pleasure boat:

- Operated a total of 186.2 hours during 1973
- Consumed an average of 1.46 gallons of fuel per hour of use in 1973.

The total number of motor driven pleasure boats was estimated at 7.3 million units in 1975. Of these boats, 48 percent were powered by gasoline engines and 52 percent by diesel engines.

The following trends are anticipated in the recreational boating sector through the year 2000:

- Increasing standards of living and personal disposable income will perpetuate the recent historical growth of the number of recreational boats.
- Greater emphasis on energy conservation and higher energy costs will lower both the average power levels and hence the average amount of fuel consumed per boat-hour and hold down any increase in the number of operating hours per boat-year.

Table II-17 gives the expected growth rates for the recreational boating sector.

TABLE II-17
Expected Growth Rates for the
Recreational Boating Sector

Parameter	Parameter Value 1975	Recent Historical Growth Rate	Growth Rate 1974-2000	Parameter Value 2000
Number of boats	7.3 million	2.80%	2.00 %	12.0 million
Operating hrs/boat	186.2 hrs	unknown	0.00 %	186.2 hrs
Fuel consumption/hr	1.46 gal/hr	unknown	(1.00)%	1.12 gal/hr

Source: Booz, Allen & Hamilton.

11 The National Boating Survey, U.S. Coast Guard, 1973.

12 Volume II, "Energy Use in the Marine Transport Industry - Industry Summary."

In the next chapter, future cargo flows and expected levels of energy use are developed based on the operational and regulatory scenarios developed in this chapter for the year 2000.

III. CARGO MOVEMENTS AND ENERGY CONSUMPTION IN THE YEAR 2000

The general method used to determine the amount of energy required by the marine transportation sector relies on:

- Defining typical or generic ships
- Identifying cargo flows on various trade routes
- Calculating the amount of cargo carried and energy required by each generic ship making one round trip on each trade route
- Calculating the number of round trips required to carry the level of trade flowing on each trade route.

This chapter presents the development of cargo movements in the year 2000 for the following four shipping sectors:

- The foreign trade sector
  - Liners
  - Tramp
  - Dry bulk
  - Tankers
  - Passenger
- The Great Lakes sector
- The Coastal shipping sector
- The Inland sector

which were used to calculate energy consumption for those industry sectors. Energy consumption calculations for the offshore, fishing and miscellaneous and pleasure sectors are based more on levels of activity rather than cargo movements. The forecasted activity levels are described in Chapter II. The energy consumption calculations for all industry sectors are given below.

1. THE FOREIGN TRADE SECTOR

Cargo movements in the foreign trade sector were based on a U.S. Maritime Administration trade forecast.[13] This forecast contained specific projections, at the 3-digit schedule A and B commodity level, for each of MarAd's 63 trade routes. Many of these trade routes are quite minor, with insignificant amounts of tonnage moving over them. Forty-six of the 63 trade routes had projected total cargo movements for the year 2000 in excess of 1,000,000 long tons per year. Of the 46 trade routes with major cargo flows, 31 have been combined by the Maritime Administration into 27 essential trade routes, as described in Appendix B, Volume II.

The tonnage moving on the remaining 15 trade routes with significant cargo flows were then combined with one of the 27 essential trade routes having similar itinerary characteristics.

(1) Tonnage Movements for Liner, Tramp, Dry Bulk and Tankers

Each 3-digit commodity for the 46 trade routes was then classified according to the type of service that would normally carry the bulk of that commodity. Table III-1 presents this classification scheme for tanker, dry bulk and tramp classifications. All other commodities were classified as liner cargo. Total tons carried were then developed for each service classification and used as the expected level of cargo movement for each trade route for the year 2000.

For tanker crude imports, the MarAd forecast allocated approximately 100 percent of the cargo to 11 trade routes. Based on this percentage distribution, the level of imports projected by a recent MIT study[14] were substituted for the MarAd forecasts.

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13 "The Long-Term Forecast of U.S. Foreign Waterborne Trade," by the Division of Economic and Operational Analysis, Office of Policy and Plans, U.S. Maritime Administration, April 14, 1977.

14 "Energy: Global Prospects 1985-2000," by the Massachusetts Institute of Technology, May 1977.

TABLE III-1
Classification of Three-Digit Schedule A & B Commodity Codes by Service Type

Service	Code	Commodity
Tanker	331	Crude oil
	332	Petroleum products
	341	Natural gas
	512	Organic chemicals
Dry bulk	041	Wheat unmilled
	042	Rice milled & unmilled
	043	Barley unmilled
	044	Corn or maize unmilled
	045	Cereals NEC
	061	Sugar
	271	Fertilizers crude
	273	Stone sand & gravel
	274	Sulfur & unroasted iron pyrits
	276	Crude materials NEC
	281	Iron ores & concentrates
	283	Ores concentrates nonferrous
	321	Coal coke briquets
	513	Inorganic chemicals
	561	Fertilizers manufacturing
	661	Lime - cement
Tramp	081	Feeding stuff for animals
	221	Oilseeds, oil nuts
	242	Wood in the rough
	243	Wood shaped or simply worked
	251	Wood pulp or wastepaper
	282	Iron & steel scrap
	286	Uranium & thorium ores & conc.
	599	Chemical products NEC
	631	Wood veneers
	641	Paper, paperboard
	671	Pig iron
	672	Iron & steel primary forms
	673	Iron & steel shapes
	674	Iron & steel plates
	675	Iron & steel hoop strip
	676	Iron & steel rails
	677	Iron & steel wire
	678	Iron & steel tubs
	679	Iron & steel castings, forgings
	732	Passenger cars, trucks, buses

Source: Booz, Allen & Hamilton.

The annual tonnage derived for the year 2000 by service type, is shown in Table III-2.

TABLE III-2
Projected Cargo Movements for the Foreign Trade Sector by Service

Cargo Movements (thousands of long-tons)				
Service	Year 1974	U.S. Flag Share [15]	Year 2000	U.S. Flag Share [15]
Liner	51,500	30.0%	148,900	40.0%
Tramp	159,000	4.0%	219,000	4.0%
Dry bulk	147,900	1.4%	502,400	10.0%
Tanker	296,500	7.2%	703,300	10.0%
Total	654,900	6.9%	1,573,600	12.0%

Source: U.S. Maritime Administration Cargo Projections and Booz, Allen & Hamilton.

(2) Energy Consumption in the Foreign Trade Sector

The cargo flows for each of the 27 trade routes developed above were coded and substituted in the Marine Transportation Energy Model, developed in Task I, to simulate cargo movements and calculate energy required for the marine transportation industry. The generic ships developed in Chapter II were substituted for those 1974 vessels contained in the model and the energy required by the foreign trade sector was calculated. The results are presented in Table III-3 on the following page.

2. THE GREAT LAKES SECTOR

Cargo flows in the Great Lakes for the year 2000 were developed for each of the following ship types:

- U.S. flag dry bulk (diesel)
- U.S. flag dry bulk (steam)
- Canadian flag dry bulk (diesel)
- Canadian flag dry bulk (steam)
- U.S. flag tug/barge
- Canadian flag tug/barge.

---

15 U.S. Flag Shares were developed based on the assumptions presented in Chapter II of this volume.

TABLE III-3
Energy Consumption in the Foreign Trade Sector
1974 - 2000

Service Type	Energy Requirements (quads)			
	1974		2000	
Liner	0.530	22.4%	1.245	22.3%
Tramp	1.080	45.8%	2.469	44.2%
Dry bulk	0.337	14.3%	0.932	16.7%
Tanker	0.333	14.1%	0.812	14.5%
Passenger	0.080	3.4%	0.134	2.4%
Total	2.360	100%	5.592	100.0%
U.S. flag consumption	0.215	9%	0.771	13.8%

Source: Booz, Allen & Hamilton.

Domestic cargo movements for the year 2000 were based on a 1974 MarAd sponsored report[16] and translake movements (between the United States and Canada) were developed from the previously cited 1977 MarAd foreign trade forecasts.

(1) Tonnage Movements for the Great Lakes Sector

Table III-4 presents a projection of Great Lakes domestic waterborne commerce for the year 2000. These movements were allocated to ship types and flag as follows:

- U.S. flag dry bulk movements - 97 percent[17] of all coal, mining products, cash grains and iron ore. These were further allocated on a 50/50 basis to steam and diesel powered Great Lakes bulk carriers.

- U.S. flag tug/barge movements - 3 percent of all coal, mining products, cash grains and iron ore, plus all other movements.

16 "Domestic Waterborne Shipping Market Analysis," A.T. Kearney, Inc., February 1974, prepared for the U.S. Maritime Administration.

17 Historical split, based on "Domestic Waterborne Trade of the United States," U.S. Department of Commerce, Maritime Administration, 1975.

TABLE III-4
A.T. Kearney - Great Lakes Tonnage Movements
1974 - 2000
(short tons)

Commodity	Projections Great Lakes
Coal	69,000
Mining products	63,000
Fuels & lubricants	11,000
Durable manufactures	15,000
Chemicals	2,000
Crude oil & natural gas	-
Cash grains	4,000
Primary iron & steel	3,000
Agricultural products	-
Grain mill products	-
Iron ore	152,000
Nondurable manufacturing	1,000
Paper	4,000
Fabricated metal products	-
Metal ores	-
Lumber	1,000
Nonferrous primary metals	-
Raw & refined sugar	-
Canned fruits & vegetables	-
Total 2000	325,000
Total 1974	196,350

Source: Booz, Allen & Hamilton.

Translake movements were projected to the year 2000 at the 3-digit schedule A and B commodity level by MarAd and are summarized by major cargo type as follows:

- Dry bulk movements - 42,036,960 short tons
- Liquid bulk movements - 3,106,000 short tons
- All other - 4,837,000 short tons.

These movements were allocated as follows:

- Dry bulk - 90 percent Canadian flag and 10 percent U.S. flag dry bulk carriers and split 50/50 between diesel and steam propulsion

- Liquid bulk and all other movements were allocated to the U.S. and Canadian flag tugs on a 50/50 basis.

These cargo movements were then combined, as shown in Table III-5.

TABLE III-5
Cargo Projections Great Lakes Sector (2000)
(short tons)

Flag	Vessel Type	Tons Moved
United States	Dry bulk (steam) Dry bulk (diesel) Tug/barge	141,000,000 141,000,000 51,000,000
Canadian	Dry bulk (steam Dry bulk (diesel) Tug/barge	19,000,000 19,000,000 4,000,000

Source: Booz, Allen & Hamilton.

(2) Energy Consumption for the Great Lakes Sector

Based on these cargo movements, an average haul distance of 540 miles[18] and the generic vessels defined in Chapter II, the energy consumption of the Great Lakes sector is given in Table III-6.

TABLE III-6
Energy Consumption in the Great Lakes Sector
1974 - 2000

Vessel Type	Flag	Energy Requirements (quads)			
		1974		2000	
Dry bulk	United States Canadian	0.036 0.008	69% 15%	0.080 0.010	79% 10%
Tanker	United States Canadian	0.002 0.003	4% 6%	0.000 0.000	0% 0%
Tug	United States Canadian	0.001 0.002	2% 4%	0.010 0.001	10% 1%
Total		0.052	100%	0.101	100%

18 U.S. Army Corps of Engineers, "Waterborne Commerce of the United States," 1974.

3. THE INLAND WATERWAYS SECTOR

Cargo movements for the year 2000 were based on the 1974 MarAd funded domestic trade forecast[19] and the changes in the operating profiles were drawn from Chapter II.

(1) Tonnage Movements for the Inland Waterways Sector

The cargo movements, shown in Table III-7, are taken from the A.T. Kearney report referenced below. This growth in tonnage is equivalent to a compound annual growth rate of 5 percent. Based on the waterborne commerce statistics, the Army Corps of Engineers reports a recent (1972 to 1974) growth rate of 3 percent per annum. For the purposes of this analysis, the growth rate for total inland tonnage is taken as one-half of the recent historical growth rate, or 1.5 percent per annum. The rational for limiting the growth to 1.5 percent per annum is due to the inherent constraints placed on tow size by channel depths and lock dimensions, as discussed in Chapter II.

(2) Energy Consumption for the Inland Waterway Sector

Based on the tonnage movements from Table III-7, and the generic vessel and operational profile given in Table II-14, the expected energy consumption is shown in Table III-8.

TABLE III-8
Energy Consumption in the Inland Waterways Sector
1974 - 2000

1974		2000	
Energy	Percent of Total Industry Consumption	Energy	Percent of Total Industry Consumption
.089	3.0	.100	1.5

Source: Booz, Allen & Hamilton.

19 "Domestic Waterborne Shipping Market Analysis," A.T. Kearney, Inc., February 1974, prepared for the U.S. Maritime Administration.

TABLE III-7

A.T. Kearney - Inland Waterway Tonnage Movements
1974 - 2000
(in thousands of short tons)

Commodity	Inland
Coal	319,020
Mining products	380,055
Fuels & lubricants	114,893
Durable manufactures	181,502
Chemicals	275,742
Crude oil & natural gas	61,058
Cash grains	122,740
Primary iron & steel	116,420
Agricultural products	46,017
Grain mill products	34,978
Iron ore	45,861
Nondurable manufacturing	24,915
Paper	51,129
Fabricated metal products	22,667
Metal ores	10,533
Lumber	18,006
Nonferrous primary metals	13,396
Raw & refined sugar	8,254
Canned fruits & vegetables	5,926
A.T. Kearney projected total 2000	1,853,112
Total 1974	599,000
Implied annual growth rate	4.4%
Recent annual growth rate	3.0%
Growth rate selected 1974-2000	1.5%
Annual tonnage 2000	789,000

Source: Booz, Allen & Hamilton.

4. THE COASTAL SHIPPING SECTOR

Coastal tonnage is expected to grow significantly due to shipments of Alaskan crude oil. In addition, as mentioned in Chapter II, the growth of coastal feeder systems is also expected. The 1974-2000 projections of tonnages by A.T. Kearney, as shown in Table III-9, has an implied annual growth rate of 7.4 percent. Even with the expected growth of the Alaskan crude trade, this rate of growth was considered excessive. By the year 2000, distribution of Alaskan crude is expected to be by pipeline from the west coast with the marine leg from Valdez to either Washington or California.

TABLE III-9
A.T. Kearney Coastal Tonnage Projections
1974 - 2000
(in thousands of short tons)

Commodity	Coastal
Coal	56,152
Mining products	37,082
Fuels & lubricants	1,065,031
Durable manufactures	94,492
Chemicals	66,840
Crude oil & natural gas	162,381
Cash grains	2,946
Primary iron & steel	3,017
Agricultural products	1,805
Grain mill products	851
Iron ore	10
Nondurable manufacturing	3,885
Paper	1,517
Fabricated metal products	1,445
Metal ores	25
Lumber	6,659
Nonferrous primary metals	309
Raw & refined sugar	6,906
Canned fruits & vegetables	3,794
A.T. Kearney projected total 2000	1,515,147
Total 1974	238,354
Implied annual growth rate	7.4%

Source: Booz, Allen & Hamilton.

The A.T. Kearney report also projected an average annual capacity growth rate for the various vessel types of:

- Tankers - 1.7 percent
- Tug/barges - 2.6 percent
- Other - 3.2 percent

over the 1971 to 2000 time period. Updating the growth rates to 1974 in order to account for scrappings and new constructions in the 1971 to 1974 period, yields expected annual capacity growth rates of:

Tankers - 2.4 percent
- Tug/barge - 2.8 percent
- Other - 2.0 percent.

For the purpose of this analysis, these annual growth rates were applied to the annual ton-miles carried by these vessel types. The average length of haul was kept constant. Tonnage movements in the coastal sector for the year 2000 are given in Table III-10.

TABLE III-10
Coastal Tonnage Movements
1974 - 2000
(in millions of long tons)

Vessel Type	Tonnage Movements	
	1974	2000
Tanker	144	267
Tug/barge	53	109
Other	16	27
Total	213	403

Source: Booz, Allen & Hamilton.

(1) <u>Energy Consumption for the Coastal Shipping Sector</u>

Based on the tonnage movements from Table III-10, and the generic vessels and operating profiles developed in Chapter II, the expected energy consumption for the coastal shipping sector in the year 2000 is shown in Table III-11.

TABLE III-11
Energy Consumption for the Coastal Shipping Sector

Vessel Type	Energy Requirements (quads)			
	1974	Percent	2000	Percent
Tanker	.071	63	.140	57
Tug/barge	.020	18	.040	16
Other	.021	19	.066	27
Total	.112	100%	.246	100%

Source: Booz, Allen & Hamilton.

5. THE OFFSHORE SECTOR

Based on the generic vessels and operating profiles developed in Chapter II and shown in Table II-14, the energy consumption of the offshore industry sector for the year 2000 is given in Table III-12.

TABLE III-12
Energy Consumption in the Offshore Sector

Vessel Type	Energy Consumption (quads)	
	1974	2000
Drilling rigs	.027	.077
Crew boats Tugboats Tug/supply boats Supply boats	.026	.095
Construction, offshore thermal energy conversion & deep ocean mining	.011	.028
Total	.064	.200

Source: Booz, Allen & Hamilton.

6. THE FISHING, MISCELLANEOUS AND PLEASURE CRAFT SECTORS

In Chapter II, it was estimated that the fishing and miscellaneous sectors would increase their energy consumption by a factor of three by the year 2000. The pleasure craft sectors operating profiles were estimated to change to:

- Number of craft - 12 million
- Operating hours per year per craft - 186.2 hours
- Fuel consumption - 1.12 gal/hour
- Fuel type - 50/50 split between gasoline and diesel.

Based on these parameters, the expected energy consumption for these sectors is shown in Table III-13.

TABLE III-13
Energy Consumption in the Fishing, Miscellaneous and Pleasure Craft Sectors
1974 - 2000

Industry Sector	Energy Consumption (quads)	
	1974	2000
Fishing and miscellaneous	0.032	0.100
Pleasure craft	0.225	0.300

Source: Booz, Allen & Hamilton.

7. ENERGY CONSUMPTION OF THE MARINE TRANSPORTATION INDUSTRY

Utilizing the latest annual trade statistics available (1974), it was estimated that the marine transportation industry currently consumes 2.9 quads annually. Table III-14 summarizes the industry's consumption projected for the year 2000 as developed in the earlier sections of this chapter, and compares it with the 1974 consumption of each industry sector. These energy consumption figures reflect the fuel or energy estimated by Booz, Allen to be required (regardless of purchase point), by all vessels (regardless of flag) when engaged in the foreign and domestic commerce of the United States.

TABLE III-14
Productivity and Energy Consumption of the
Marine Transportation Industry

Industry Sector	1974 (estimate)			2000 (forecast)		
	Long Tons of Cargo Moved (millions)	Energy Consumed (quads)	%	Long Tons of Cargo Moved (millions)	Energy Consumed (quads)	%
Foreign trade						
U.S. flag	45.0	0.215	7	188.8	0.771	12
Foreign flag	609.9	2.145	73	1,384.8	4.821	72
Great Lakes	175.3	0.052	2	334.8	0.100	2
Inland waterways	535.8	0.089	3	704.5	0.100	2
Coastal	213.0	0.112	4	403.0	0.300	4
Offshore	-	0.064	2	-	0.200	3
Pleasure craft	-	0.225	8	-	0.300	4
Fishing and miscellaneous	-	0.032	1	-	0.100	2
Total	1,579.0	2.934	100.0	3,015.9	6.692	100.0

Source: Booz, Allen & Hamilton.
NOTE: Percentages may not add to 100 percent due to rounding.

Prior to the Arab oil embargo in 1974, which led to large increases in world fuel prices, the question of fuel consumption rates and their reduction were either not addressed by operators or given a relatively low priority due to the minor impact that changes in the rate of fuel consumption had on total transportation costs. Consequently, a shortage of data exists concerning energy consumption in the industry, and until recently, few comprehensive studies have been initiated to determine the industry's energy intensiveness. As a result, our estimates of the energy consumption of the industry carry a degree of uncertainty. The methodology developed to calculate energy consumption for both 1974 and the year 2000 required a number of assumptions. These major assumptions were:

- In the foreign trade shipping sector, a generic vessel was defined and chosen to represent all vessels of that type operating on a given trade route, as defined by the Maritime Administration. In reality, vessels frequently deviate from these assumptions. The degree to which these generic vessels accurately represent a cross section of each trade and sector is unknown. However, they are representative of actual vessels employed on these trades.

- In the maritime industry, vessel capacity is generally measured in deadweight[20] tons or cubic feet and trade flows are measured in tons. A deadweight utilization factor, based on historical averages was applied to each generic vessel type in order to compensate for variations in both cargo densities and vessel utilization. In reality, the amount of a vessel's weight carrying capability actually used varies significantly based on factors such as:

    - Vessel operator
    - Type of cargo carried
    - Industry sector
    - Season of the year
    - Direction of the trade flow
    - Shipping technology used
    - Water depth of ports and harbors on the vessel's itinerary

- In almost all bulk trades and to a lesser degree, liner trades, the trade flows are not balanced as far as tonnages moving in both directions. In the bulk trades, vessels typically spend half their life in ballast. The extent to which the search for backhaul cargoes affect operating profiles and energy consumption is unknown.

- The analysis of the recreational boating sector relied on 1973 U.S. Coast Guard data describing populations, sizes and operating patterns. These 1973 operating patterns were applied to 1975 recreational boating population statistics. The

20 Deadweight — A term describing the weight carrying capacity of a cargo ship, it includes the weight of cargo, crew, stores, and fuel and is measured in long tons of 2240 pounds.

extent to which operating profiles identified in 1973 accurately represent those occurring in 1975, is unknown.

- The fishing and miscellaneous, and offshore sectors are so diverse that meaningful operating profiles could not be developed. As a result, the analysis used for these sectors differs from that developed for the other sectors.

These factors affect the calculated marine transportation energy consumption figure of 2.9 quads for 1974. It is estimated that the uncertainty associated with the estimate of total industry energy consumption could reach plus or minus 25 percent. The projected energy consumption figure of 6.7 quads is also subject to the same qualifications and, in addition, is only as accurate as the cargo forecasts and the future operating and technological scenarios upon which it is based.

IV. IDENTIFICATION AND EVALUATION OF POTENTIAL RESEARCH AND DEVELOPMENT PROGRAMS

The energy-related technology base of the commercial marine transportation industry is composed of the following 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 a separate study and are not discussed in this report.[21]

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 using current dollars

- Step 3 — Calculate the energy impact associated with the introduction of each program area in the U.S. flag fleet for activity levels and cargo movements estimated for 1974 and 2000

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21 Refer to report entitled "Evaluation of the Alternatives for Contingency Fuels in the Commercial Marine Transportation Industry," by Booz, Allen for the Department of Energy, Contract No. EY-76-C-03-1175.

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

- Step 5 — Estimate costs of DOE program actions in each of the program areas based on current dollars.

Key to the analysis in steps 1 through 3 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 two years, 1974 and 2000. Cargo movements 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, and cargo carrying capacity, as shown in Chapter II.

Each program area to be analyzed can be introduced into this generic U.S. flag fleet by varying 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.

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 turbines and combined cycles (GTCC)
  - Closed cycle gas turbines (CCGT)

- Propulsors
  - Contra-rotating propellers (CR)
  - Propellers in nozzels (PIN)
- Hydrodynamics
  - Submerged air cushions (SAC)
  - Cutaway hulls (CH)
  - Tunnel sterns (TS)
  - Hull maintenance and smoothing (HMS)
- Vessel operations
  - Vessel routing (VR)
  - Plant tuning (PT).

These 15 program areas were then applied to the series of 35 generic vessels described in Tables IV-1 and IV-2. These tables also identify the application of each program area by industry sector and generic vessel type for 1974 and 2000, respectively.

The applicability of each program area was based on engineering and technical considerations. These considerations are discussed in the appendices that address each program area. Each program area is briefly discussed in the following sections.

(1) <u>High Pressure/Temperature Reheat Steam Plants (HPTRS)</u>

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 IV-2, 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

TABLE IV-1
Application of Research and Development Programs
to Generic U.S. Flag Vessels for the Year 1974

Industry Sector	Vessel Type	DWT	HP	Speed Knots (mph)	Main Propulsion Plants							Propulsors		Hydrodynamics				Vessel Operations	
					HPTRS	SSD	DBC	AD	NAHBE	GTCC	CCGT	CR	PIN	SAC	CH	TS	HMS	VR	PT
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							●	●										

Source: Booz, Allen & Hamilton.

TABLE IV-2
Application of Research and Development Programs
to Generic U.S. Flag Vessels for the Year 2000

Industry Sector	Vessel Type	DWT	H.P.	Speed Knots (mph)	Fuel Rate (16/SHP-HR)	Deadweight Utilization Factor	Program Areas: Main Propulsion Plants							Propulsors		Hydrodynamics				Vessel Operations	
							HPTRS	SSD	DBC	AD	NAHBE	GTCC	CCGT	CR	PIN	SAC	CH	TS	HMS	VR	PT
Foreign Trade	Container	14,800	9,000	17.6	.37	.50			•										•	•	
	Container	20,000	24,000	22	.37	.50			•				•	•					•	•	
	Container	23,000	25,000	22	.37	.50			•				•	•					•	•	
	Container	28,000	40,000	25	.47	.50	•	•				•							•	•	•
	Ro/Ro	12,500	22,000	25	.37	.33			•			•	•	•					•	•	
	Ro/Ro	20,000	35,000	25	.47	.33	•	•				•	•	•					•	•	•
	Ro/Ro	22,000	36,000	25	.47	.33	•	•				•	•	•					•	•	•
	Barge	38,000	35,000	22	.47	.33	•	•				•	•	•					•	•	•
	Carriers	49,000	39,000	22	.47	.60	•	•				•	•	•					•	•	•
	Break Bulk	25,800	26,000	22	.37	.40			•				•	•					•	•	
	Tramp	11,760	7,000	15	.37	.40			•										•	•	
	Dry Bulk	30,000	10,000	15	.37	.96			•										•	•	
	Dry Bulk	45,000	12,000	15	.37	.96			•										•	•	
	Dry Bulk	60,000	13,500	15	.37	.96			•										•	•	
	Tankers	20,000	7,000	14	.37	.80			•										•	•	
	Tankers	40,000	9,000	14	.37	.80			•										•	•	
	Tankers	65,000	14,000	15	.37	.80			•										•	•	
	Tankers	150,000	20,000	15	.47	.80		•				•	•	•	•	•	•	•	•	•	•
	Tankers	300,000	36,000	15	.47	.80	•	•				•	•	•	•	•	•	•	•	•	•
Inland Rivers	Tug	12,061	2,171	(7.2)	.37	1.00			•	•	•										
Coastal	Tanker	44,000	12,500	(15)	.37	.80			•								•	•	•		
	Tug	13,000	2,250	(8)	.37	1.00			•	•	•										
	Other	16,500	22,000	(22.5)	.47	.33		•						•					•		
Great Lakes	Dry Bulk	30,000	10,000	(11)	.47	.96	•	•													
	Dry Bulk	30,000	10,000	(11)	.37	.96			•	•	•										
	Tug	11,000	3,000	(9)	.37	1.00			•	•	•										
Offshore	Tug				.37				•	•	•								•		
	Tug/Supply				.37				•	•	•								•		
	Supply				.37				•	•	•								•		
	Crewboat				.37				•	•	•								•		
Pleasure	None									•	•										
Fishing & Misc.	None				.37					•	•								•		

Source: Booz, Allen & Hamilton.

discussion of this program area is contained in Appendix A.

(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. In this evaluation, 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. In our analysis, 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 an 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 oceangoing 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 regardless 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 Nozzels (PIN)

Locating a propeller within a nozzle increases 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 generic U.S. flag tankers larger than 150,000 DWT. 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 generic U.S. flag tankers larger than 150,000 DWT. 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 generic U.S. flag tankers larger than 150,000 DWT. 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 oceangoing vessels. Hull maintenance and smoothing programs were applied to all generic U.S. flag oceangoing 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 oceangoing 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) Plant Tuning (PT)

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. Plant tuning programs were applied to all generic U.S. flag steam powered vessels for the 1974 cargo movements. Plant tuning programs were not applied to cargo movements for the year 2000, as plant upkeep programs not now existing were assumed to be part of the projected technology base. A more detailed discussion of this program area is contained in Appendix D.

2. STEP 2 — DETERMINATION OF ECONOMIC IMPACTS

Operating and cost parameters for 1974 were developed for each generic vessel type. These baseline parameters are given in the appendices. Cost impacts associated with the implementation of each program area were assigned to the following two categories:

- Changes to acquisition costs
- Changes to daily operating costs

  - Wages
  - Stores and subsistence
  - Maintenance and repair
  - Insurance.

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 — QUANTIFICATION OF 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

- Estimates 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 GOVERNMENT FUNDED PROGRAMS

Estimates of funding requirements, durations, and earliest possible start dates for each of the 15 program areas were made.

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 program funding estimates reflect estimated funding requirements necessary to resolve operational questions that are currently inhibiting full acceptance by the marine industry.

The results of the analysis and the conclusions and recommendations are presented below.

6. RESULTS OF THE ANALYSIS

The results of the analysis described above, are presented in Table IV-3. Two general conclusions can be drawn from these results.

(1) All Program Areas Identified Show a Net Economic Benefit Based on 1974 Costs

As shown in columns three and four of Table IV-3, 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 analyses were based are considered conservative:

TABLE IV-3
Results of Econcmic and Energy Impact Analysis

LEVEL OF TECHNOLOGICAL RISK	PROGRAM AREA	RANGE OF REDUCTION IN REQUIRED FREIGHT RATE (%) (1974)		ENERGY CONSERVATION POTENTIAL 1974 (% OF U.S. FLAG CONSUMPTION)	ENERGY CONSERVATION POTENTIAL 2000 (% U.S. FLAG CONSUMPTION)	POTENTIAL PROGRAM START	PROGRAM DURATION (YEARS)	ESTIMATED FUNDING REQUIREMENTS TO LOWER RISK CATEGORY (MILLIONS OF $)		
		MINIMUM	MAXIMUM					LOW TO COMMERCIALIZATION	MEDIUM TO LOW	HIGH TO MEDIUM
LOW	SSD	1.0	8.2	1.5	12.7	FY-78	2	0.500	–	–
LOW	PT	0.2	1.4	1.4	0.0	FY-78	–	0.000	–	–
LOW	VR	0.0	10.0	0.0	0.0	FY-78	–	0.000	–	–
MEDIUM	DBC	2.1	5.2	3.6	11.2	FY-78	2	UNKNOWN	3.000	–
MEDIUM	HMS	0.0	3.3	3.1	6.2	FY-78	1	"	0.250	–
MEDIUM	GTCC	0.0	5.18	[illegible].2	2.9	FY-78	2-3	"	4.000	–
MEDIUM	TS	0.2	1.0	0.6	0.9	FY-78	1	"	0.300	–
MEDIUM	CB	0.9	1.6	0.5	3.1	FY-78	2-3	"	4.000	–
MEDIUM	HPTRS	3.7	5.9	1.4	2.8	FY-78	10	"	3.000	–
MEDIUM	PIN	0.7	0.7	4.0	0.3	FY-78	2-3	"	1.000	–
MEDIUM	CH	0.6	0.6	0.0	1.4	FY-78	1	"	0.300	–
HIGH	AD	0.0	0.0	10.2	6.7	FY-80	5	"	UNKNOWN	2.000
HIGH	NAHBE	2.4	3.6	5.4	2.9	FY-79	3	"	"	1.000
HIGH	CCGT	5.2	[illegible].4	1.4	2.7	FY-80	6-7	"	"	50.000
HIGH	SAC	1.6	1.6	0.0	0.7	FY-78	1	"	"	0.400

Source: Booz Allen & Hamilton.

- No construction or operating subsidies
- Residual and diesel fuel priced during 1974 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:

- Slow speed diesels
- High pressure/temperature reheat steam plants
- Closed cycle gas turbines

showed the greatest percentage reduction in RFR.

(2) Five Program Areas Have Energy Reduction Potential Greater Than 5 Percent in Either 1974 or 2000

Columns five and six of Table IV-3 show the potential for energy reduction in the event the programs are applied to the U.S. flag vessel types in accordance with Tables IV-1 and IV-2.

Five program areas had energy reduction potentials greater than 5 percent in either 1974 or 2000:

- Slow speed diesels (SSD)
- Diesel bottoming cycles (DBC)
- Hull maintenance and smoothing (HMS)
- Adiabatic diesels (AD)
- Naval Academy heat balance engine (NAHBE).

The energy conservation potential is defined as the difference between the energy required to transport the base year cargo movements, either 1974 or 2000, with the generic fleet defined for that year and the energy required to transport the same cargo movements with a modified fleet reflecting the introduction of the applicable R&D programs.

7. TWO PROGRAM AREAS ARE RECOMMENDED FOR FUNDING BY THE DEPARTMENT OF ENERGY (DOE)

Based on the energy savings potential identified in Table IV-3 and the status of current R&D efforts by DOE or other organizations, the program areas in:

- Diesel bottoming cycles (DBC)
- Adiabatic diesels (AD)

are recommended for funding by the Department of Energy. The programs are complementary and potential applications exist in all seven industry sectors, as shown in Table IV-4.

TABLE IV-4
Applications of Recommended Program Areas

Program Areas	Industry Sector: Foreign Trade	Great Lakes	Inland Rivers	Coastal	Offshore	Pleasure	Fishing & Misc.
Diesel Bottoming Cycles	•	•	•	•	•	•	•
Adiabatic Diesels		•	•	•	•		•

Source: Booz, Allen & Hamilton.

The elements of these program areas are discussed below.

(1) 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 containing the following elements be initiated:

- Develop specifications and the design of a prototype exhaust heat recovery unit for installation on an inland river towboat be started. Such a program is estimated to cost \$400 to \$550 thousand.

- Construct, test and install the prototype. This program is estimated to require funding of \$1.3 to \$1.5 million.

- Operate the system for a year as a demonstration project to prove the savings potential. Costs associated with this element is estimated at $300 thousand.

It is expected that this demonstration project would span approximately two years and cost approximately $2.0 to $2.5 million.

(2) Recommended Program Elements in the Adiabatic Diesels Program Area

Basic research is currently being conducted in the adiabatic diesel program area by the U.S. Army and the Cummins Engine Company. The goal of the U.S. Army-sponsored program is to develop a smaller, lighter, and more efficient main battle tank engine.

Reliability and operating criteria for a military diesel and a commercial marine diesel are extremely different. Given the expected benefits of the adiabatic diesel, as discussed in Appendix A, the results of current research should be reviewed next fiscal year with an expected participation directed toward developmental research for marine application.

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.

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 oceangoing 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.

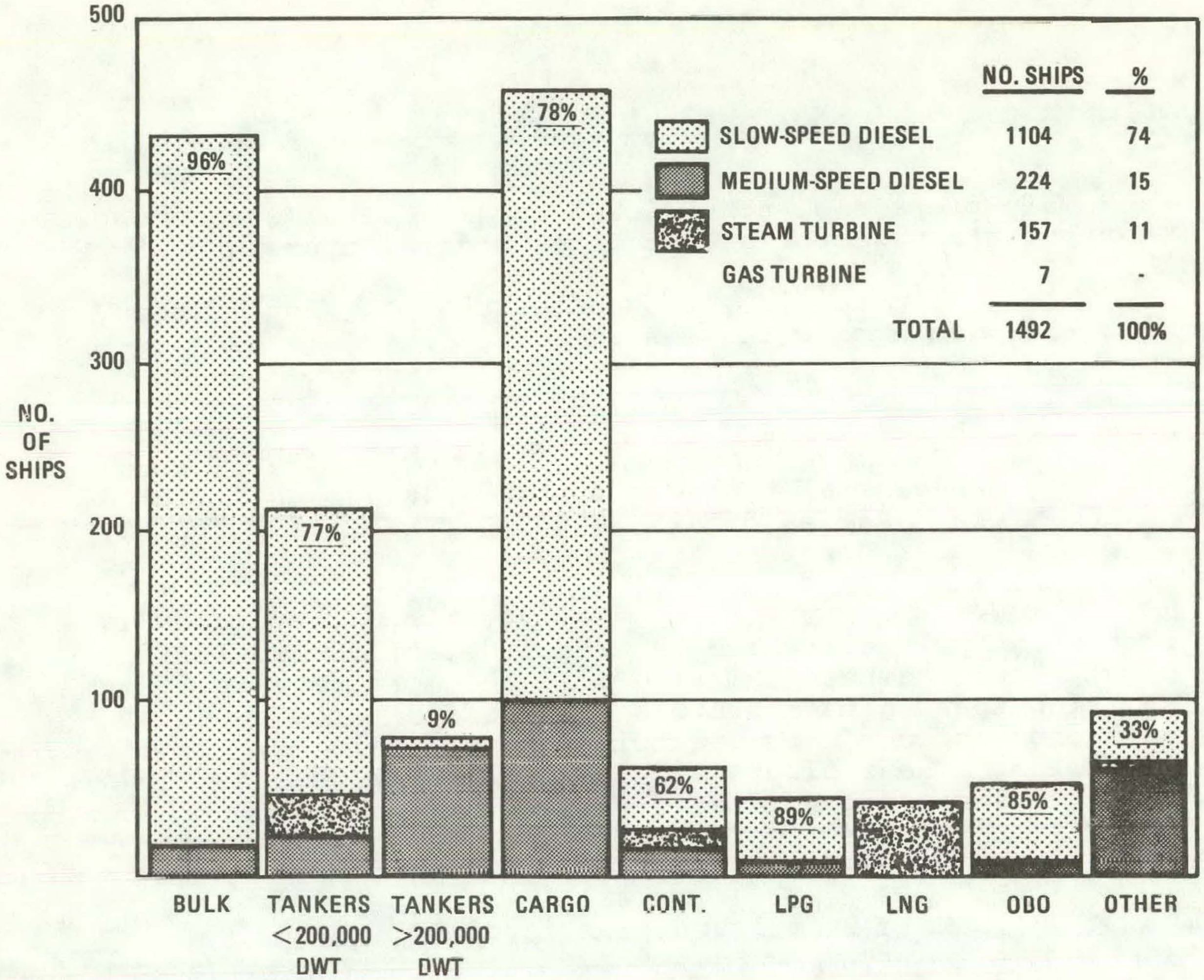
The U.S. oceangoing merchant fleet has traditionally been steam powered, while the remainder of the world's merchant fleet has been shifting more and more towards medium and slow speed diesel propulsion. Today, three types of main propulsion plants are being installed in any quantity worldwide. These 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

Source: Booz, Allen & Hamilton.

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 turbines. 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).

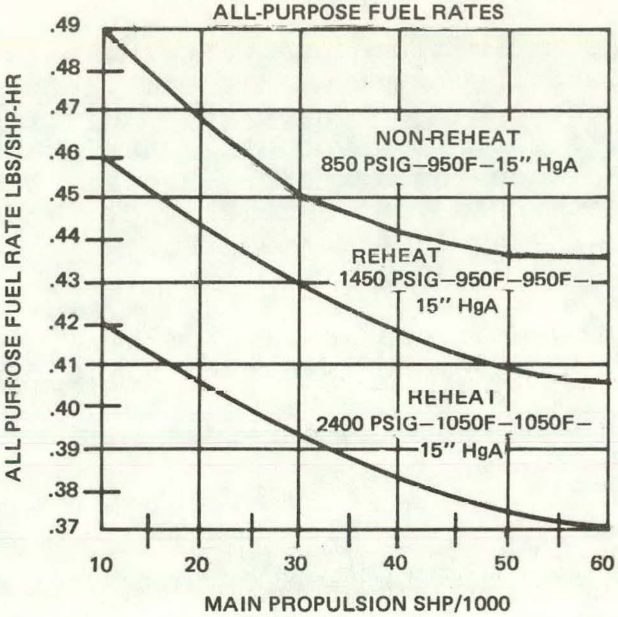
Each of these program areas is discussed below.

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

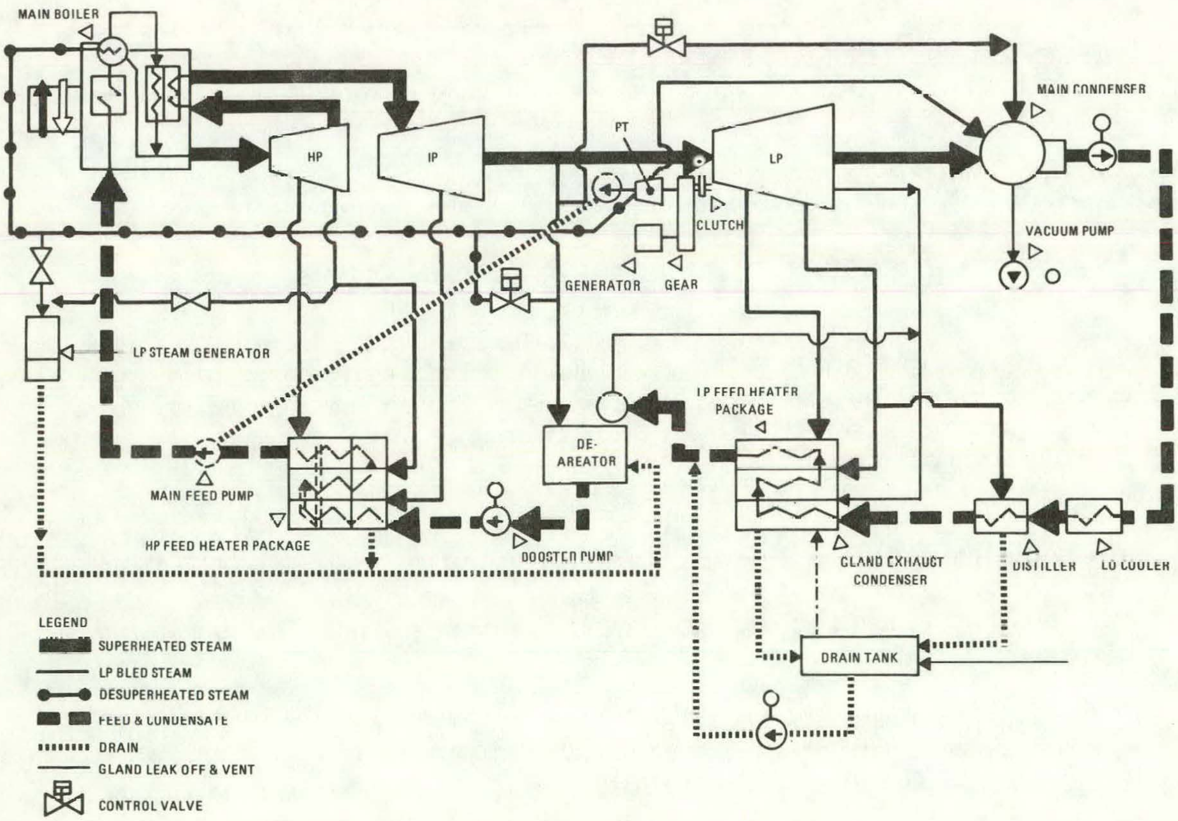
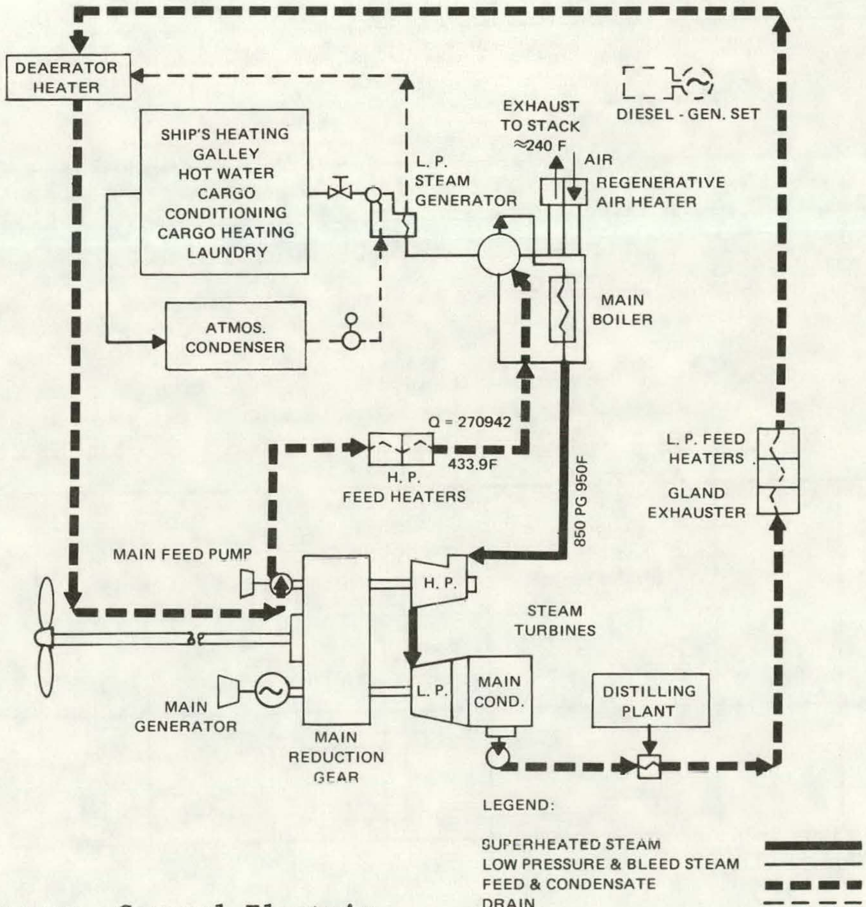


FIGURE A-3
Flow Diagram for G.E. 2400 PSIG/1050^{O}F/1050^{O}F
Reheat Steam Plant

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 nonreheat 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 (lb/SHP-hr)		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

Source: Booz, Allen & Hamilton.

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:

- Increased lube oil consumption
- 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 (lb/SHP-hr)		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

Source: Booz, Allen & Hamilton.
NOTE: M&R costs include increased lube oil costs.

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 U.S. Department of Energy, the U.S. Maritime Administration and the U.S. Navy. 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 (lb/SHP-hr)		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

Source: Booz, Allen & Hamilton.

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 $2.0 to $2.5 million.

4. ADIABATIC DIESELS

Cummins 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 Cummins 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 Cummins 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.

Cummins 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

Source: Booz, Allen & Hamilton.

The Army and Cummins expect to eventually use composite 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, as alternative lubrication systems able to withstand the higher operating temperatures have not as yet been evaluated.

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 (lb/SHP-hr)		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

Source: Booz, Allen & Hamilton.

Production and maintenance and repair costs of the adiabatic diesel were estimated by Cummins 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).

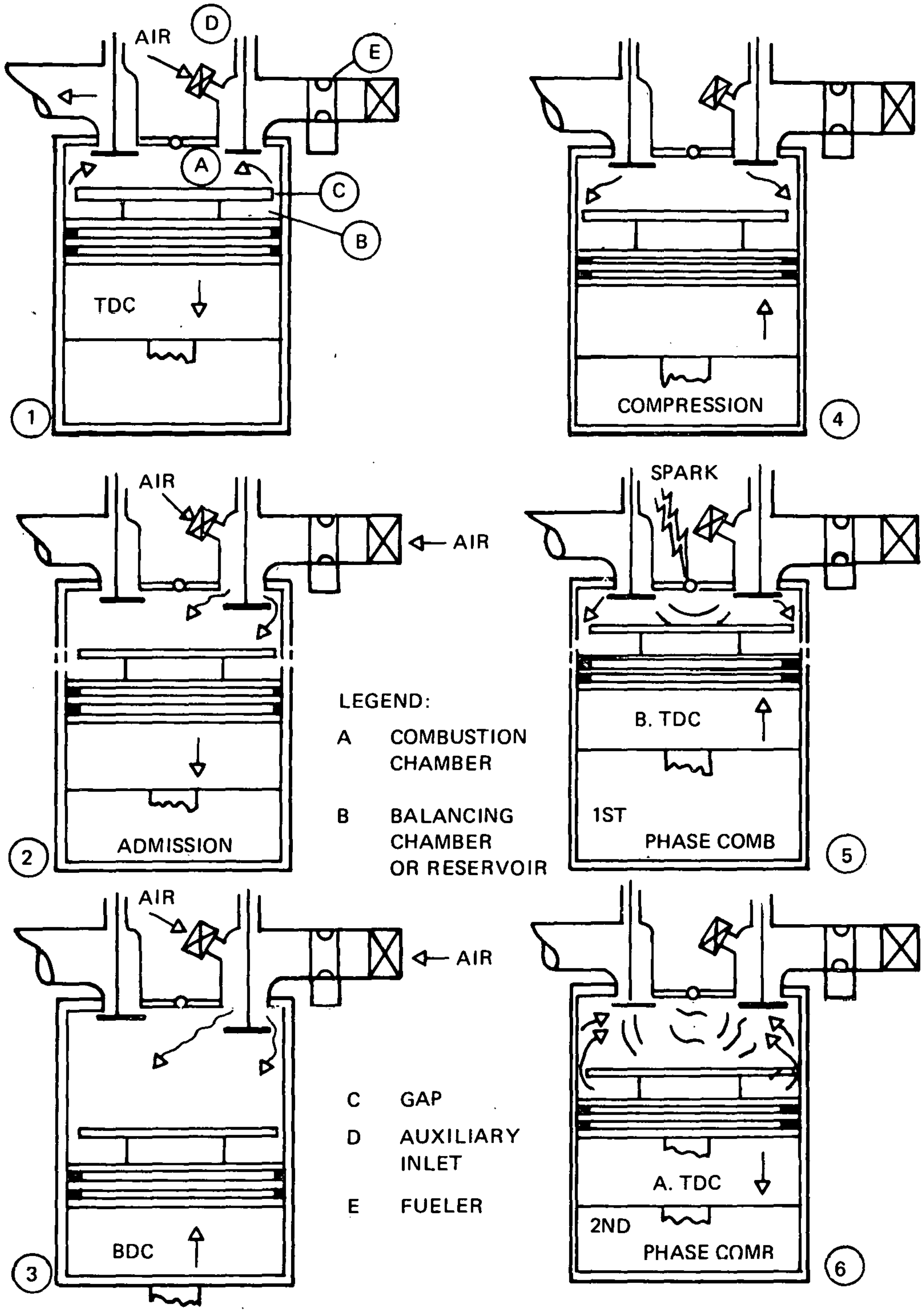
3. Charge is stratified with a very lean composition just above the piston.

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)."[1]

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



Source: "Naval Academy Heat Balance Engine," Blaser, Pouring, Keating & Rankine, 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 (lb/SHP-hr)	
		Baseline	NAHBE
Great Lakes Tanker	2,676	.37	.34
Great Lakes Tug	–	.37	.34
Coastal Tug	–	.37	.34
Inland River Tow Boat	–	.37	.34

Source: Booz, Allen & Hamilton.

(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 DOE 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.

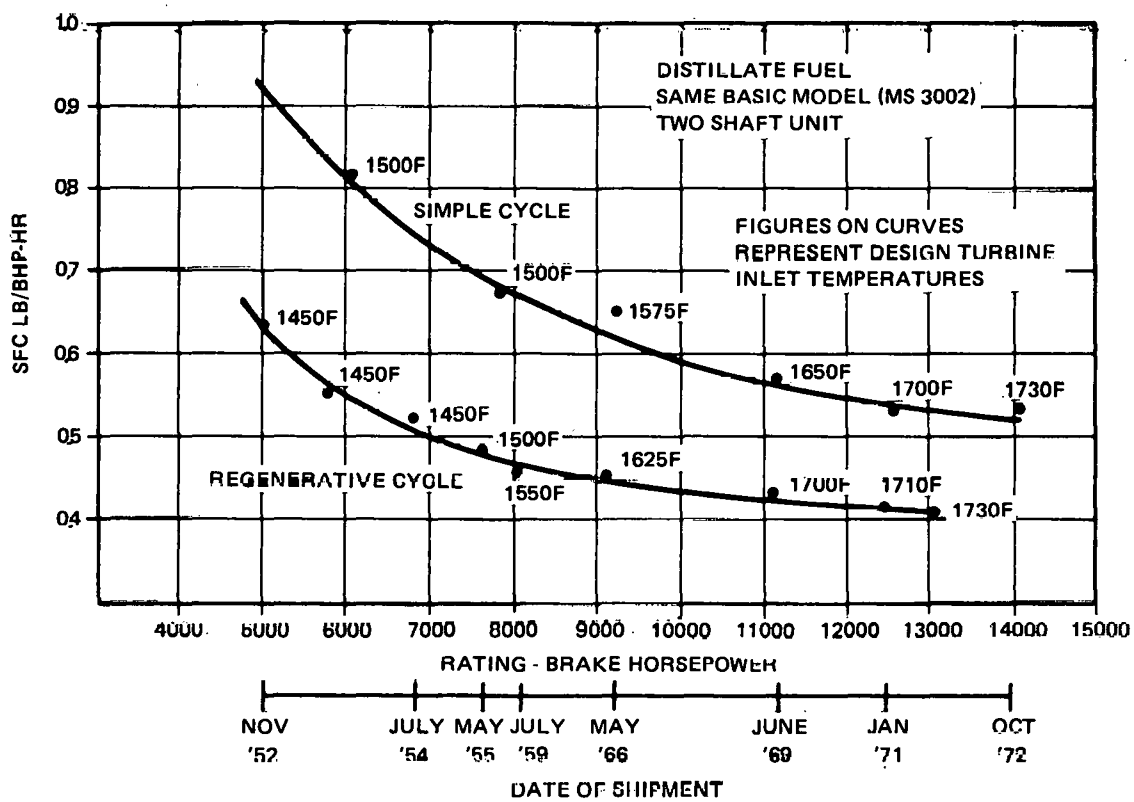
Table A-9
Specific Fuel Consumption Rates of Current Heavy Duty Marine Gas Turbines

	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.

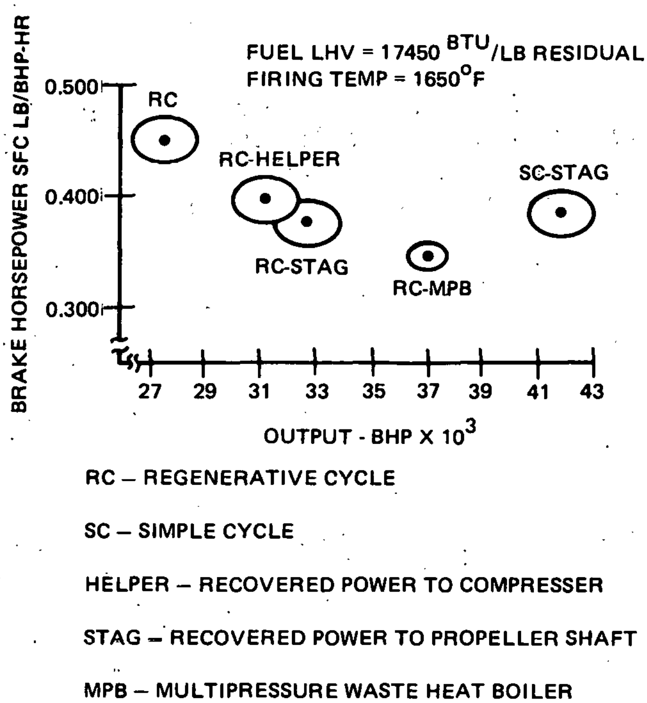
Improvements to the specific fuel consumption of the heavy duty gas turbine will come from two areas; upgrading of the basic turbine through higher firing temperatures and improved cycle efficiencies through the use of Rankine bottoming cycles.

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 Rankine 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



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 Rankine 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 megawatts, 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 regardless 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 (lb/SHP-hr)		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	860
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

Source: Booz, Allen & Hamilton.

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

(2) Program Elements

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

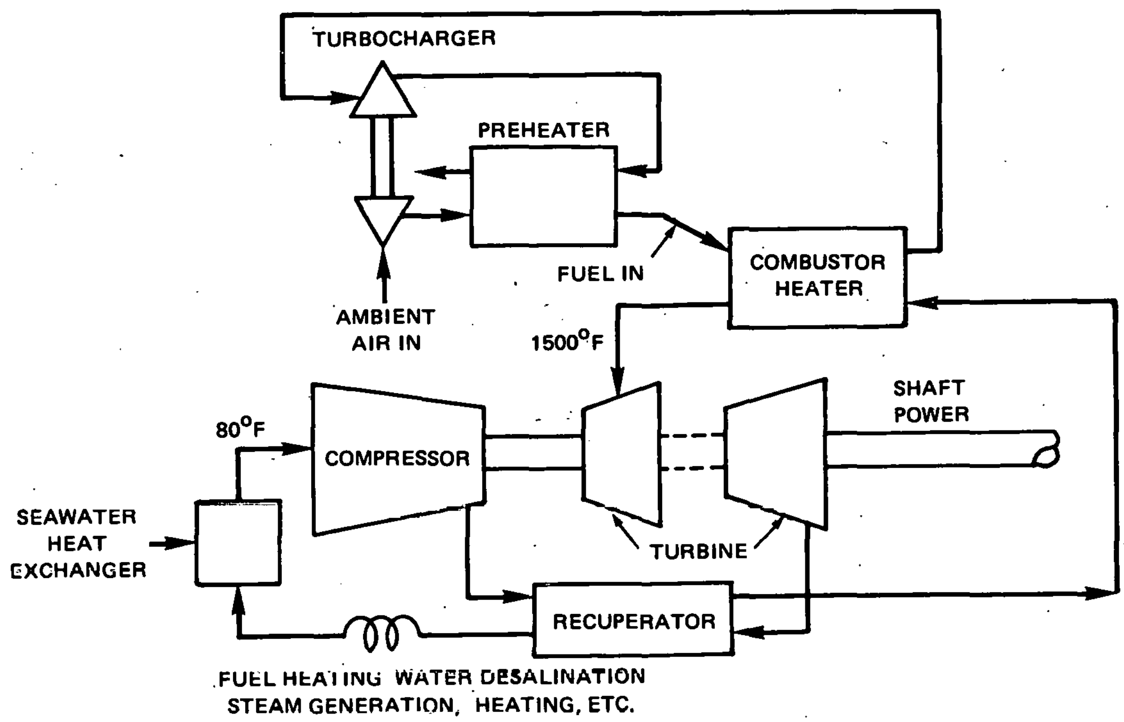
- Higher turbine inlet temperatures through use of ceramic materials being developed for the closed cycle gas turbine program
- Bottoming cycles, either organic or steam, and multiple pressure boilers.

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 on 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:

- U.S. Department of Energy
- 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 (lb/SHP-hr)		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

Source: Booz, Allen & Hamilton.

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 DOE, EPRI and the Navy is completed.

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

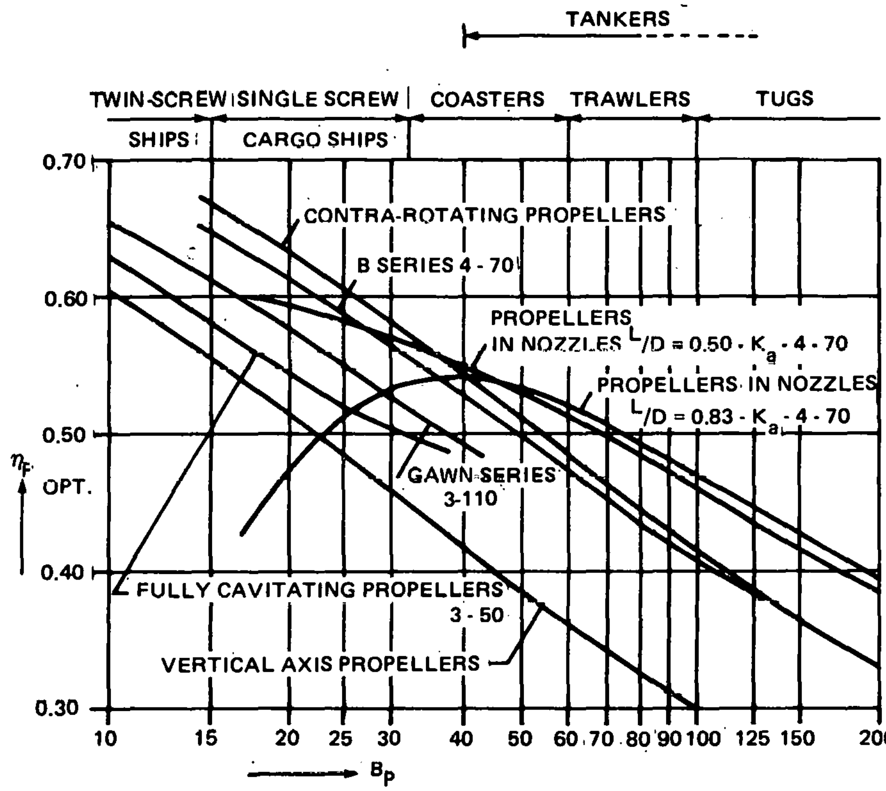
No. of Screws	Propulsive Efficiency (%)
1	70 - 80
2	60 - 70
4	55 - 65

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,



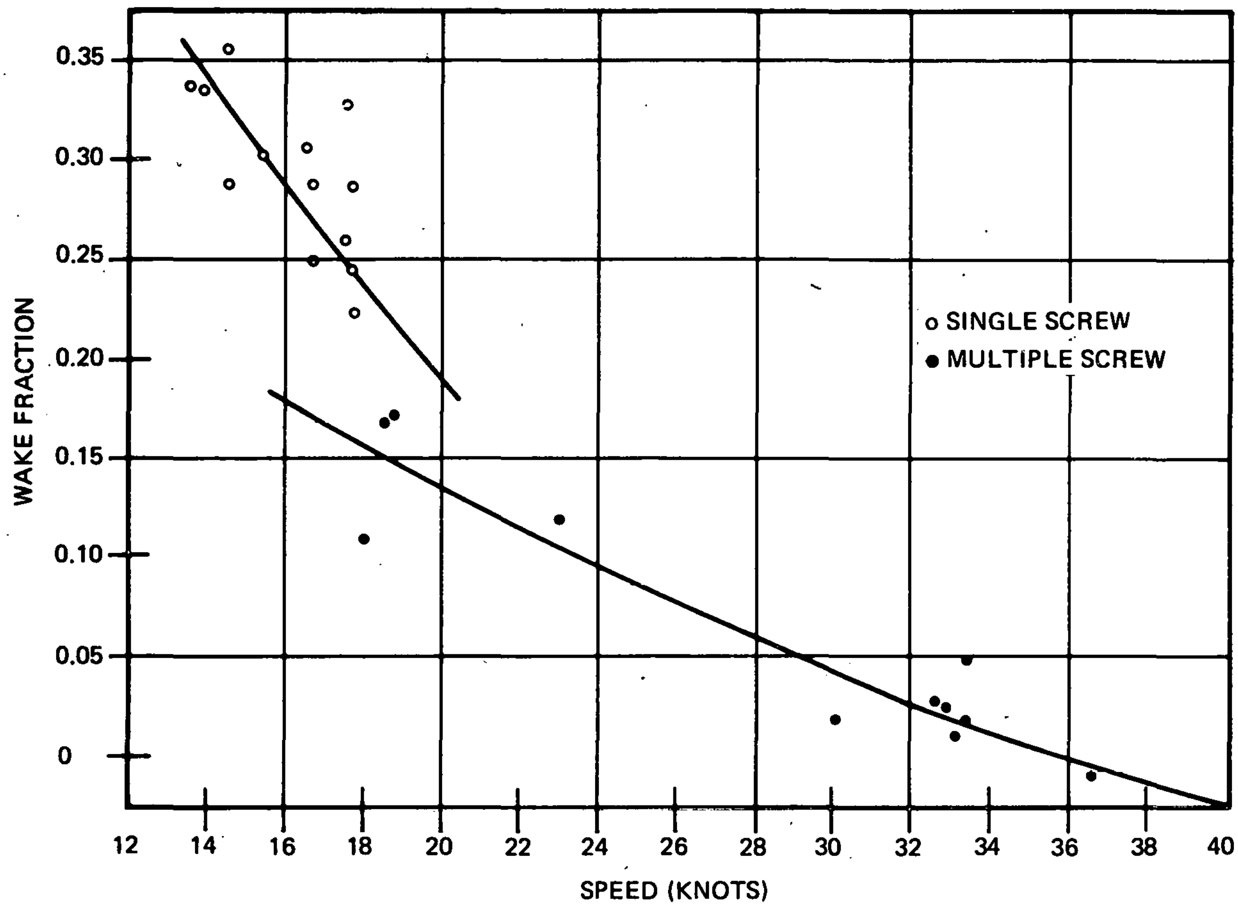
Source: "Marine Engineering," Seward, Society of Naval Architects and Marine Engineers

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 points 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 (PIN).

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	38,640	57.0	58.4	1,334	1,444	1,639	1,667

Source: Booz, Allen & Hamilton.

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

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 Totem Shipping Company. Totem 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 oceangoing 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

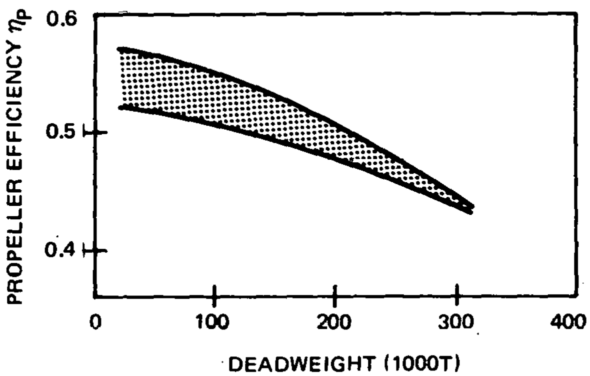
Vessel	Ship Type	Dead-Weight	Horse-Power	Delivery	Shipyard
Kronoland	Tanker	131,450	25,000	1970	Eriksberg
Golar Nichu and 3 Sister Ships	Tanker	215,780	30,000	1970-1972	Kawasaki
Thorsaga	Tanker	279,750	34,200	1973	Mitsui
Hoegh Hood	Ore/Oil Carrier	244,670	33,000	1973	Kawasaki

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

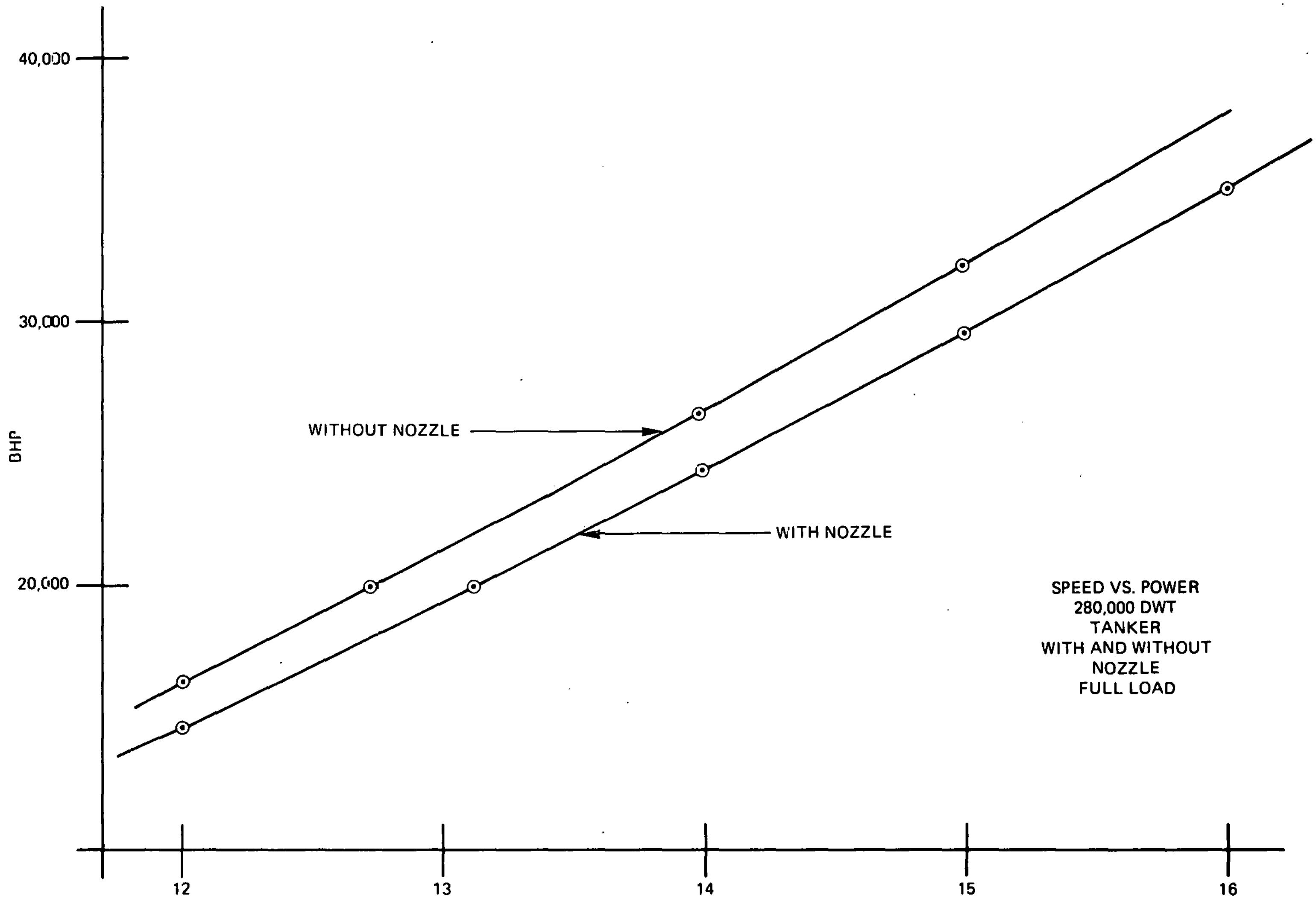
Staal, United Kingdom and Norwegian companies who design and produce ducted propellers for large vessels. The cost for installation of a ducted propeller has been estimated as approximately twice that of a conventional propeller.

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 nozzles 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.



Source: Booz, Allen & Hamilton.

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

Tablc 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	PIN	Baseline	PIN	Baseline	KORT
Tanker	150,000	20,000	18,400	68.6	69.0	1,608	1,616

Source: Booz, Allen & Hamilton.

(2) Program Elements

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 stern (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 eliminates 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.

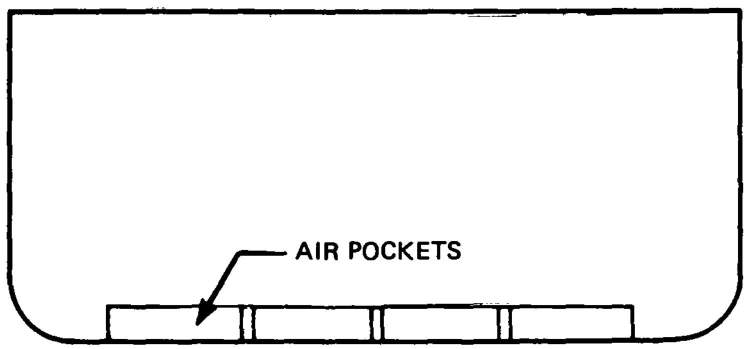


FIGURE C-1
Submerged Air Cushion Hull Form Cross Section

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

Source: Booz, Allen & Hamilton.

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

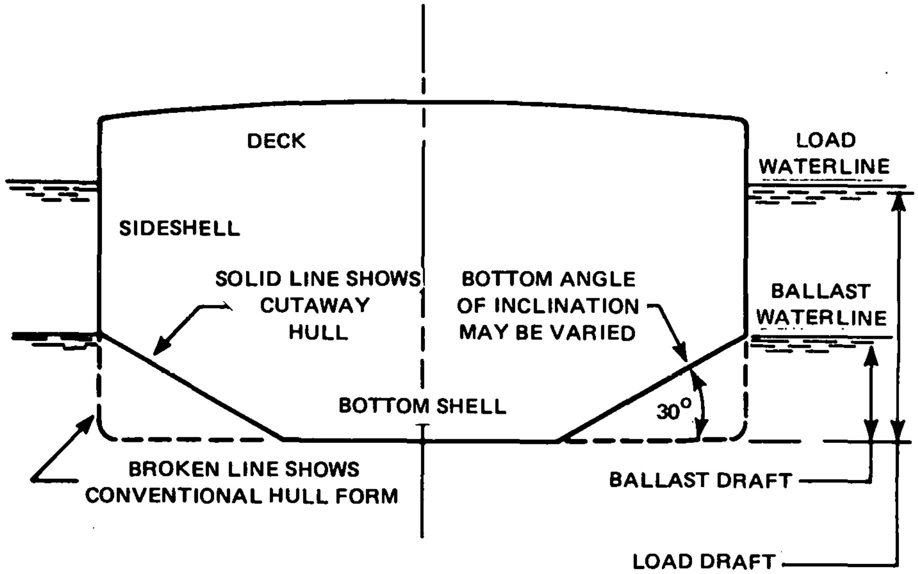
Additional work in this area concerned with:

- 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 Consultative 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 waterline. 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

Source: Booz, Allen & Hamilton.

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.

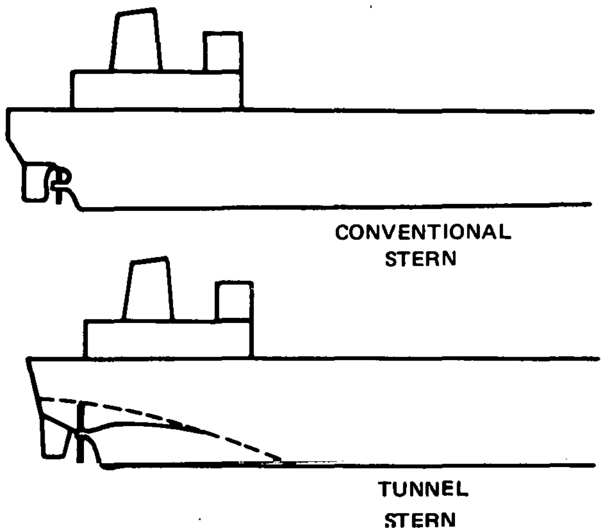


FIGURE C-3
Conventional and Tunnel Sterns

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

Vessel Type	DWT	Horsepower		Acquisition Costs ($/Day)	
		Baseline	TS	Baseline	TS
Dry Bulk	20,000	8,000	7,600	8.0	8.6
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

Source: Booz, Allen & Hamilton.

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:

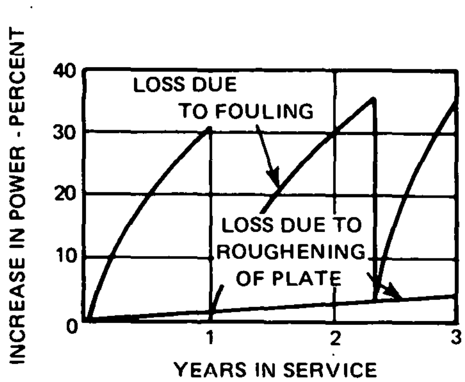
- Increased costs due to a larger propeller and other equipment changes, such as propeller shaft, larger reduction gears, etc.
- Operational cost savings due to reduced fuel consumption
- Increased efficiency of the propulsive system
- Increased resistance of the hull

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 year's 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.

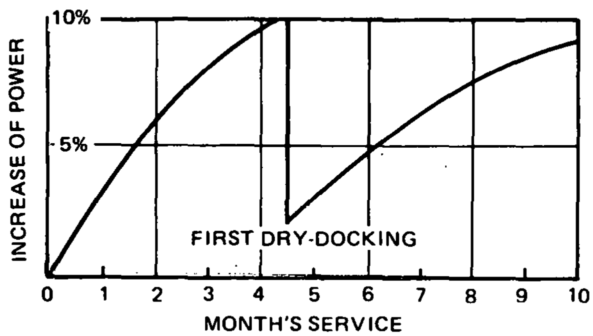
The effect of hull fouling and corrosion on a vessel's fuel consumption is tremendous. Increases in the power required to maintain a given speed can range up to 30 percent per year as shown in Figure C-4. These are the results of full-scale tests carried out on the Koningan Elisabeth, a cross-channel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

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[1] (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.

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1 "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 copolymer), 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.

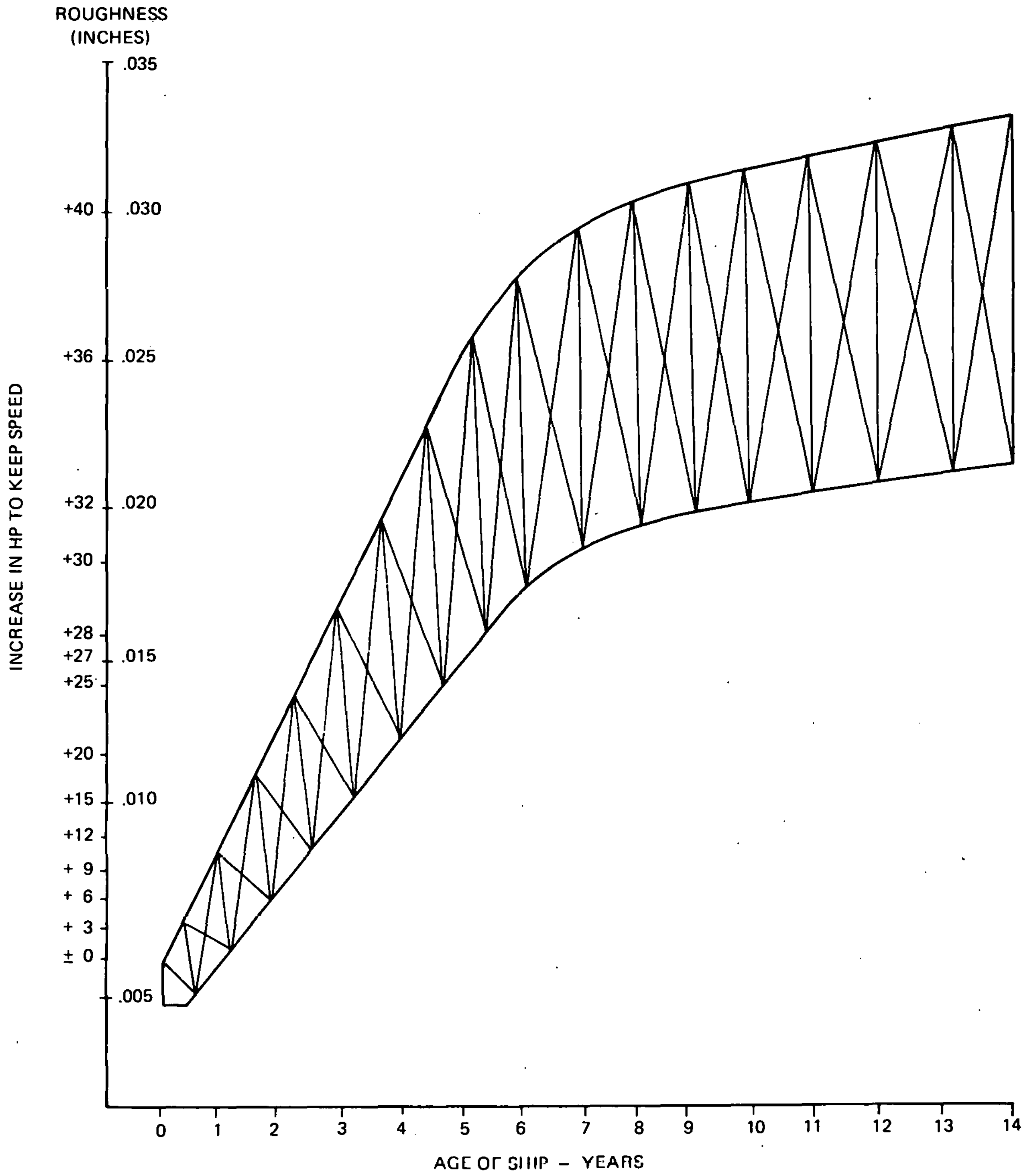
In addition, the polishing action takes place more rapidly in areas of high turbulence which results in a smoothing of the paint film. Results of full-scale applications show an actual decrease in resistance over time as the hull surface polishes itself.

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) Applications

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	904	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

Source: Booz, Allen & Hamilton.

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

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

- Vessel routing (VR)
- Plant tuning (PT).

Each of these is discussed below.

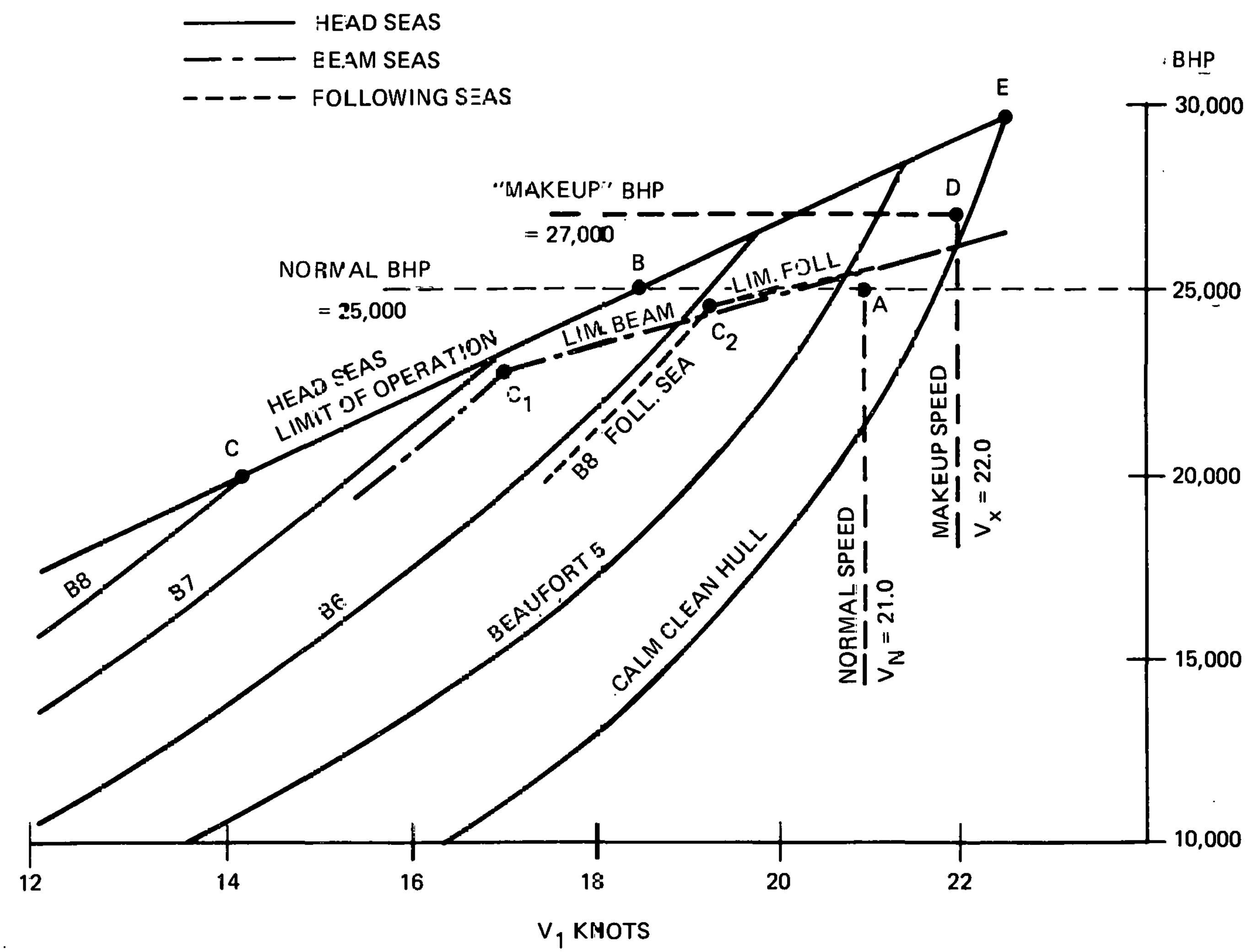
1. VESSEL ROUTING

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^{o} 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 per 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. PLANT TUNING (PT)

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 plant 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. Merchant Marine Academy cadets, returning to school after their sea-duty period, 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 plant tuning 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 plant tuning 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 DOE-funded program in this area is anticipated.

Table E-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 %	Fuel Rate lb/shp-hr.	Fuel Type	U.S. First Costs (millions of dollars)	$/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

Source: Booz, Allen & Hamilton.

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