Chapter 5

Status and Trends in Ship Design and Operating Technology

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Status and Trends in Ship Design and Operating Technology

OVERVIEW

This chapter discusses technologies in ship design and operations and identifies those that offer significant opportunities to U.S. shipping and shipbuilding enterprises. Trends in the design, construction, and operation of merchant ships of the world's leading commercial maritime nations are reviewed and analyzed. The information base included surveys conducted by the U.S. Maritime Administration (MarAd),[1 2] the Ship Technical and Operations Committee of the Society of Naval Architects and Marine Engineers (SNAME),[3] and a study of "Productivity Improvements in U.S. Naval Shipbuilding' conducted by the Marine Board of the National Research Council.[4]

This chapter also discusses current federally sponsored marine research and development (R&D) and strategies for upgrading technologies of both ship production and ship operations.

The ebb of the economic cycle of any industry is the time when technological improvements are needed most to rejuvenate the industry and to support its continued operation at a profitable level when it has recovered from its slump. Unfortunately for the maritime industry and for many others, the reverse is most frequently experienced. R&D funds are withdrawn, and the training of people in new technologies is reduced to the point that when recovery comes, the industry is far behind its competitors in vying for business and in reestablishing itself. Investments in R&D are vital to U.S. maritime capabilities in the future.

Although the Merchant Marine Act of 1936 laid the groundwork for a modern merchant marine, the ship types in the resultant merchant fleet after World War II did not give a competitive edge over foreign fleets. Compounding the problem, postwar reliance on World War 11 ships, and various conversions of these vessels, produced an aging fleet with few modern, high-capacity, efficient ships necessary for competitive operations.[5]

Following the Merchant Marine Act of 1970, a large peacetime shipbuilding program was started and resulted in a number of technologically advanced ships, designed for specific missions and cargoes. Now, in 1983, the U.S. merchant shipbuilding and ship-operating industries are at a low point. Only a few new merchant ships are under construction in the United States. Much of the U.S.-flag fleet is aging and does not meet the technological level of our foreign competitors.

The impetus given by the Merchant Marine Act of 1936 in the form of construction and operating differential subsidies is no longer a popular strategy for increasing the strength of the U.S. merchant marine. Furthermore, the technological innovations that gave strength to the shipbuilding program that followed the 1970 Act now have been dissipated.

1"Research and Development Program Briefing, Maritime Administration, U.S. Department of Transportation, Jan. 27, 1983.

2"Merchant Vessel Propulsion Service Margins," Maritime Administration, U.S. Department of Transportation, contract No. MA-80-SAC-01067, prepared by The Baham Corp., Columbia, Md., January 1983.

3"Assessment of Maritime Trade and Technology," questionnaire for SNAME Ship Technical Operations Committee, for the U.S. Congress, Office of Technology Assessment, October 1982.

4"Productivity Improvements in U.S. Naval Shipbuilding, prepared by the Committee on Navy Shipbuilding Technology, Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington, D. C., 1982.

5"Evolution of Vessels Engaged in the Waterborne Commerce of the United States," by Robert Taggart, RT-41802, prepared for the Corps of Engineers, Historical Division, January 1983.

STATUS AND TRENDS IN SHIP DESIGN

In the past two decades there have been numerous changes in the makeup of the world fleet. Tankers have increased in size four to five times, to 250,000 to 500,000 deadweight tons (dwt); dry-bulk carriers have increased over twentyfold in total tonnage, and unitized cargo ships of all kinds have been introduced. Until the oil embargo of 1973, ship operators continued to increase speed and propulsion power to improve service. However, current trends have been to reduce or hold service speed constant to control operating costs. The major effort today to increase transport efficiency and competitive position is via increased hull size and faster turnaround time in port.

The healthiest sector of world shipping today is composed of those fleets engaged in the liner trades. A forecast presented by Kruse projects an increase of double to quadruple the number of twenty-foot-equivalent units (teu) between 1980 and 2000.[6] Liner shipping would continue to be dominated by the demand for containerized cargo. There would also be a continued shift from breakbulk cargo into unitized cargo trade. Shipments in the form of neo-bulk, roll-on/roll-off (RO/RO), and lift-on/lift-off (LO/LO) cargo will continue to grow in volume. Shipping between developed ports will utilize large, highly efficient carriers. High-value and perishable cargo must be shipped at normal to high optimum-carrier-service speeds. Low-value cargo will be shipped on an unscheduled basis. Medium to small multipurpose freight carriers capable of handling both breakbulk and unitized cargo will serve lesser developed ports. These ships gradually will displace tramp breakbulk freighters.

As discussed in chapter 2, worldwide liquid- and dry-bulk trades probably will remain essentially level or increase only a moderate amount in the near term. Bulk shipping will be heavily affected by changes in world energy consumption patterns. A transition period in which petroleum consumption is declining gradually in favor of coal and other alternative sources will ensure a continuing soft market for crude-oil tankers. Major scrapping within the world supertanker fleet already has begun and will continue into the late 1980's. Coal exports, particularly from the United States, will continue to grow well beyond the next two decades. Likewise, bulk shipping of grain will be a product sector with continuing strength due to an increasing world population. This trade is particularly significant for U.S. interests.

Technological Innovation *in Liner Trades*

Perhaps the most important strategy for maritime industry improvement is to provide means to recognize potentially profitable technological innovations, to test and evaluate them, and to promote their incorporation in ship production or operation.

The evolution of containerization illustrates a successful maritime innovation. The present integrated, intermodal container system began with an experiment conducted by a land transportation company, McLean Trucking Co., which acquired Pan American Steamship Co. and was later renamed Sea-Land. The innovation to be tested was the shipboard carriage of trailers between U.S. gulf coast ports and New York. From this beginning, the present container system has evolved through actual trials under field conditions.

The first step, in 1956, consisted of carrying the trailers on specially constructed spar decks of tankers operating between New York and Houston. Having demonstrated the feasibility of the shipboard storage and carriage of trailers, the company designed a RO/RO trailer ship, an idea that was abandoned at the contract plan stage in favor of the more technically feasible and economical LO/LO principle. Six general cargo ships were converted to full containerships, equipped with shipboard cranes for loading and discharging. The ships carried 226 35-ft containers. The technical and economic attractiveness of the system was demonstrated under these field operations. After this successful demonstration, the company instituted an intercostal service in 1966, and by 1976 had entered foreign trade with the system. Today, Sea-Land Industries, Inc., is one of the world's largest containership operators,

[6]Hans Jakob Kruse, "The Future of the Liner Industry," *Shipping 2000*, Conference Proceedings (London: British Shippers Council, June 19, 1979), p. 49.

Photo credit: Sea-Land Industries

While containerization permits a vessel to be in and out of port in 1 day—as opposed to a week or more for breakbulk shipping—it is also a capital-intensive industry

The importance of the implementation stage also is evident in the adoption of containerization by Matson Navigation Co. This company, which operated a service between the U.S. west coast and Hawaii, was having economic problems and decided that port productivity was a factor that required improvement. To find a solution, Matson, in a move uncharacteristic of the industry, established an inhouse research department to analyze its shipping operation and suggest improvements. Using systems analysis techniques, including a computer simulation model, this department was able to analyze a number of possible changes. These studies pointed to containerization as the best option to consider for further development and trial demonstration.

Like Sea-Land, Matson introduced the new system cautiously by carrying containers on the decks of conventional freighters. The success of these demonstrations led to conversion of a C-3 type ship to a full containership. During the planning and development as well as the implementation stage, Matson not only developed new technology-e. g., special terminal cranes—in support of the innovation, but also addressed the problems of labor and customer acceptance. Therefore, as the trial implementation progressed, the feasibility of containerization was demonstrated both in terms of technical design and in terms of meeting labor and marketing requirements. The Matson project showed that field demonstration of the feasibility of an innovation can be strengthened by a formal evaluation strategy.[7]

Handling freight via breakbulk methods has given way to unitized cargo shipping. This includes palletized cargo, containers, barges, and trailers. The major advantage is that most high-volume cargo is now shipped in standard sizes. Shipping in standard container sizes has allowed development of specialized cargo-handling equipment. Ports worldwide now have invested large sums in adapting dedicated berthing areas to loading and unloading of standard 20- and 40-ft containers.

In the design of the latest generation of containerships, the trend is toward multipurpose service on major high-density Atlantic and Pacific routes. On some mid- to short-haul routes this trend is rapidly displacing the breakbulk freighter service. The consensus of opinion seems to indicate that the additional flexibility gained by this type of vessel offsets the higher cost of construction and lost deck space. This type of vessel can moor in almost any conventional berth by use of angled and skewed ramps. Specialized handling systems are not required for RO/RO cargo. Two contrasting design philosophies have developed among experienced shippers. The first is that each ship should be fitted with the necessary crane capacity to unload itself. The second is that all self-unloading will be via forklift trucks, even for containers. The choice of design will be dictated by the particular trades of each shipper.

Cargoes requiring refrigeration, such as food products including meat, fruit, and fish, have been transported in "reefer" ships in refrigerated holds or compartments. In recent years individually refrigerated containers have steadily displaced cargo carried on specialized ships. One of the new developments that will cause a significant shift of high-

7"Innovation in the Maritime Industry, " Maritime Transportation Research Board, Commission on Sociotechnical Systems, National Research Council, National Academy of Sciences, Washington, D. C.} 1979.

value perishable cargo from the air-freight market to containerized cargo is the development of controlled atmosphere containers. Perishable produce now shipped via air can be shipped in modified 40-ft refrigerated containers at one-fourth the cost, with far superior quality produce delivered to the customer. These containers use inert nitrogen gas to lower the oxygen level inside the container.

Technological Innovation in the Bulk Trades

The major bulk trades include crude and refined oil products, liquefied petroleum gas (LPG) and liquefied natural gas (LNG), iron ore, bauxite and other ores, coking and steam coal, grains for human and animal consumption, and neobulk cargo such as logs and other forest products. While most predictions for crude-oil shipping over the next two decades are modest, the demand for other types of bulk carriers should not be as bleak.

Although the United States pioneered the use of specialized ships such as barge-carrying ships, we have fallen behind the foreign competition in capitalizing on these technological innovations. The tug-barge concept was considered to be only an attempt to get around manning requirements that never achieved any economic success. The rest of the world forged ahead of the United States in the construction and utilization of large crude-oil carriers, and only in the development of the LNG systems and product carriers have we attained parity with or superiority over other nations in liquid-bulk carrier-design innovations. It is foreseen that marine transportation systems of the future will utilize many more ships that are specifically designed for particular cargoes and trade routes.

If the latter situation does come to pass, it may or may not be good news for the U.S. maritime industry. In the past, the United States has demonstrated proven capabilities in optimizing ship designs to match specific operational requirements. However, we have not moved rapidly into such markets and, in some cases, the operational requirement evaporated by the time the production began. An example of this was the U.S. building program for supertankers that only began after the rest of the world had built tankers far in excess of demand. Current projections for new very large crude carriers (VLCCS) indicate no requirements until the mid-1980's depending on the rate of scrapping. New designs of crude carriers will not likely exceed deadweight tonnages of 250,000,

Most recent industry announcements indicate that a prolonged period of consolidation and scrapping of excess tonnage in crude tankers will be required to restore freight rates to values with which carriers can survive. A recent commentary in The Motor Ship notes that "recent levels of scrapping may be historically high, but in the context of the problem, it is miniscule: it would take 5 years of scrapping at double the current rates before a balance of tonnage is achieved.

Operators will be looking for conservative gains such as propulsion fuel economy and the ability to burn heavy fuels. Two-stroke diesel engines will remain dominant as long as there are no precipitous losses of oil supplies. Major emphasis will be placed on increasing docking cycles to 5- or 6-year intervals when feasible. There will be a need for improvement in hull coatings and protection systems beyond current levels to accomplish this. Bulk trades will be the most likely for introduction of steam plant innovations. Slower optimum service speeds than the traditional 15 to 16 knots will predominate. Most tanker operators have been running crude carriers at reduced service speed to offset in part excess capacity.

The demand for barge carriers such as LASH and Seabee may continue to increase at a steady pace. These two designs were U.S. innovations. There are two major reasons for building barge-carrier systems. The first is that barges can be loaded and unloaded at inland ports and floated by tug to a rendezvous with the mothership. Loading and discharge of lighters (barges) on the mothership is rapid. The second advantage accrues to barge carriers when serving developing countries with limited capacity to handle containerized cargo. Barge carriers are self-sufficient and do not need elaborate shore-support facilities. The primary reason that they have not fulfilled expectations is that they are expensive large vessels that require a continuous supply of cargo to be profitable. Large deck openings or catamaran hulls are costly to construct

"'Viewpoint," ***The Motor Ship,*** vol. 63, No. 748, November 1982, p. 5.

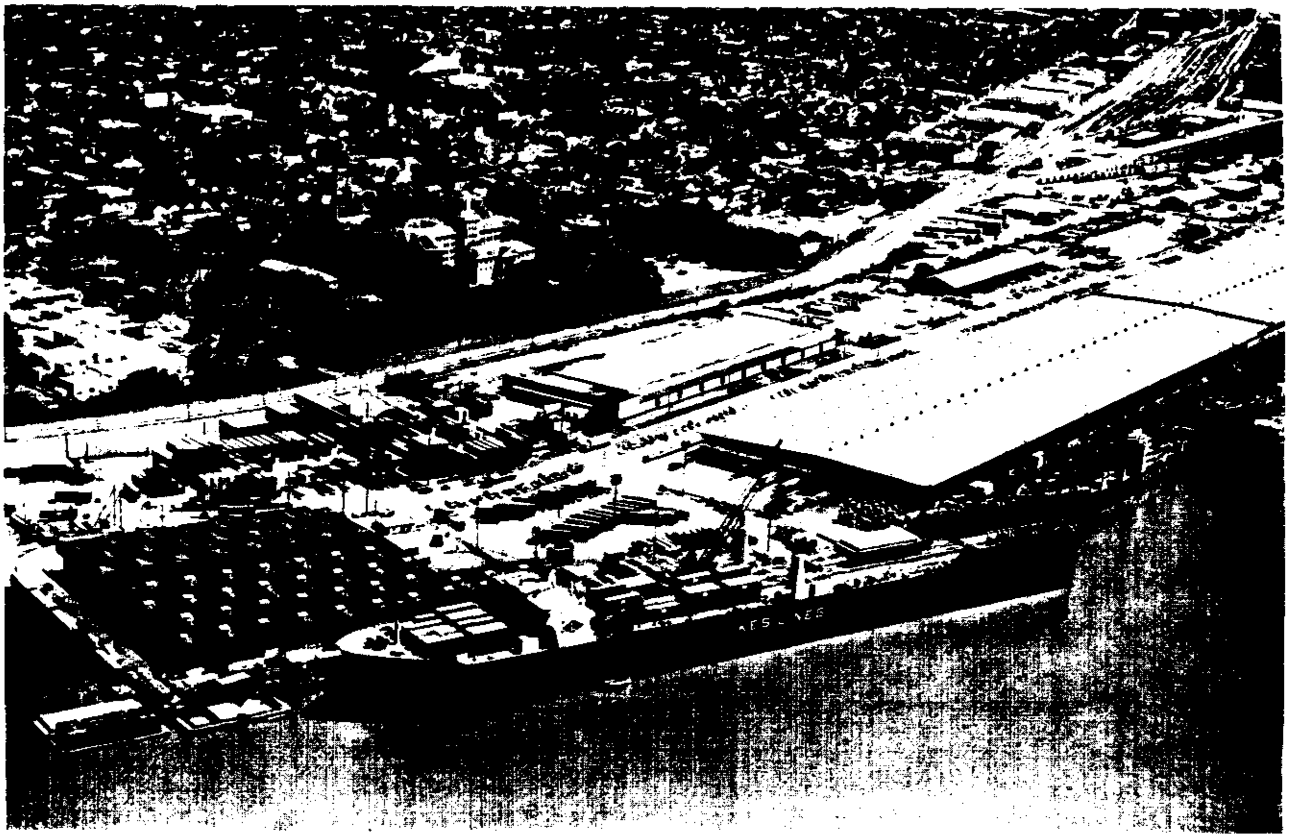

Photo credit: Por7 of New Orteans

A "Seabee"-type barge carrier unloading in the Port of New Orleans

and some designs have very elaborate stern or bow openings. Barges, unlike containers, have not been standardized from one carrier to another. Also, storage and handling of unmanned barges in port causes problems.

Arctic Transportation

The severe environmental conditions in the Arctic require innovative technology for developing resource recovery systems. Arctic energy and mineral resources are believed to exist in abundance; however, exploration, production, and transportation will continue to be expensive relative to other alternatives in the near term. In addition to oil and gas, the Arctic contains large reserves of coal and deposits of copper, lead, and zinc.

The Federal role in Arctic research has been one of cooperation with industry. Petroleum industry projects have included the use of Government laboratories and expert personnel. Some programs have been jointly managed and funded. Continuing study is needed on the engineering properties of sea ice. The dynamics of sea ice interactions with ships and marine structures during wave-driven storm conditions are critical, as is the collection of ice/keel and ice/scour data and analysis of ice/seafloor-interaction dynamics. The effects of the force of large ice features, such as pressure ridges, on test structures need to be better understood through field studies.[9]

Future expansion of Arctic oil and gas production activities will require new technology. Various transportation methods have been proposed, including icebreaking tankers, submarine tankers, LNG barges and ships, and air-cushion vehicles for logistics support. The United States has a techno-

9 'Research Needs for Arctic and Sub-Arctic Region, Staff paper, Office of Technology Assessment, U.S. Congress, June 15, 1982, p. 21.

Photo credit: University of Alaska

Future transportation in arctic conditions may require icebreaker support such as shown here

logical lead in some of the above areas but is considered to be behind the U. S. S. R., the Scandinavian countries, and Canada in icebreaking design. Among present plans are shipments of Canadian crude to Japan passing through the Bering Strait on icebreaking tankers. However, navigation in the Beaufort and Chukchi Seas now depends completely on ice conditions.[10]

In addition to the potential for future offshore oil and gas discoveries that would lead to increased shipping needs in the Arctic, there are proven reserves of land minerals in Alaska, including coal and iron ore that could be developed soon. Northwestern Alaska has large coal deposits that could be extracted and shipped if new port facilities were built. New ports have been planned near Nome. Since the entire transport network for any major Alaskan mineral development would need to be constructed, considerable shipping needs are evident.

The presently producing North Slope oilfields in Alaska also contain considerable quantities of gas that have never been produced. Industry plans of 5 years ago were to build a gas pipeline from the North Slope through Canada to the U.S. Midwest. Those plans have never been carried out, mainly because of the huge capital requirements of such a pipeline. Other methods of transporting the North Slope gas have been considered—including constructing a fleet of LNG tankers for the purpose. It appears now that some shipping scheme is still a viable option. Improved shipping technology as well as lower costs would be major factors in such a decision.

There have been numerous studies of the feasibility of submarine tankers for carrying crude oil or LNG. Conceptual designs of both nuclear and conventionally powered versions have been proposed. At present, no sea tests have been conducted. The General Dynamics Corp., Electric Boat Division, has proposed versions of submarine tankers that they claim could be economically competitive with surface icebreaking tankers or pipeline systems.[11]

[10]Ibid., p. 77.

[11]"Submarine LNG Carrier Proposed by General Dynamics for Arctic Regions," *Maritime Reporter,* Mar. 1, 1982, p. 12.

The Beaufort Sea is usually frozen 8 months of the year and in the process of freezing or thawing for another 3 months. Oceangoing barges without icebreakers can be used for resupply only once a year. To extend this window, the use of icebreaking air-cushion barges has been tested by VECO-International and Global Marine Development, Inc. The development and successful testing of a 100-ton cargo-capacity barge was financed by Sohio Alaska Petroleum Corp. and Shell Oil Co. at Prudhoe Bay. [12]

One important consideration that affects any oil and gas development in the Arctic is that of pollution prevention and control. There is limited knowledge about the environmental effects of oil spills in Arctic regions, but most indications are that they would be more severe and persistent than in warmer ocean waters. In any case, special care in design and operation of both production and transportation systems seems to be warranted to avoid pollution problems. New systems also will be required for oilspill cleanup if that becomes necessary.

Arctic shipping—especially from the Alaskan North Slope or the Beaufort Sea—is subject to a number of political considerations as well. For example, shipping through either the Bering Straits or the Northwest Passage is subject to international agreements for both rights of passage and pollution prevention. Agreements with both the U.S.S.R. and Canada regarding the extent of any offshore resource jurisdictions are also a factor. Any major development also will need to be considered in light of possible impacts on Arctic environments and the native people of the region,

Advanced Hull Forms

Monohull displacement ships make up the total of the existing merchant fleet, and most design concepts are still based on traditional hull forms operating in the 15- to 30-knot speed range. There are very few exceptions. Advanced or higher speed hulls eventually may find their niche in commercial service but probably not under present economic conditions nor for employment in any major commercial cargo service. Advanced hull development has occurred only in the market categories of offshore supply and passenger/ferry vessels. These hull form concepts include:

- hydrofoil-supported vehicles;
- air-cushion vehicles (ACVS);
- surface effects ships (SESS); and
- catamarans and small-waterplane-area twin-hull (SWATH) vessels.

Both surface-piercing hydrofoils and ACVS have been built for the small passenger vessel and ferry markets during the past several decades, but these vessels cannot compete with displacement hulls in cargo-carrying capacity. Their poor seaworthiness at high speeds also has limited their use to relatively confined waters.

Totally submerged hydrofoils and SESS overcome the seaworthiness problem to some extent since they have the potential of providing high-speed performance in relatively rough seas. Several offshore supply vessels have been built in the United States using the SES principle.

Catamarans are being used as pusher tugs at sea, and SWATH vessels have seen some commercial application in servicing ocean drilling and work platforms in heavy seas. However, these vessels have limitations when extended to other uses, and the SWATH vessels especially have been hampered by high construction costs.

A related hull development is the semisubmersible hull used primarily for drilling rigs and ocean construction platforms. Here, an abovewater column-supported platform is carried by totally submerged twin hulls. This configuration has marked advantages in maintaining station in heavy seas, but its transit and variable load-carrying abilities are limited.

In general, advanced-hull forms undoubtedly will continue to be investigated for certain commercial applications but, in each case, cargo-carrying capacity and economic feasibility will be the major determinant of commercial viability.

Trends in Propulsion Technology

The propulsion plants in service today for merchant ships have been subject to continuous development during the past decades. This development

[12] "Air Cushion Vehicle Successfully Tested for Arctic Icebreaking," *Maritime Reporter*, Mar. 1, 1982, p, 12.

has been generated principally by concern for future fuel availability and the economic burden of increasing fuel costs on shipowners.

Most of the U.S.-flag fleet has steam-powered machinery. The traditional steam-turbine powerplant represents the culmination of many extended development programs in both the electrical utility and the maritime industries. The development has reached a level of diminishing returns with respect to cycle efficiency. The maritime industry, however, has not followed electric utility practice to the same level of development because it has not been justified economically for a powerplant at typical marine ratings. Secondly, electric utility units operate for very long periods at constant speed; consequently, the refinement of those units is not practical for a marine engine which operates at variable speeds, reverses rotation, and has to be on-line within a few hours. The expected improvements in marine steam-turbine powerplants will come in four general areas: further refinements in the steam cycle, use of boiler reheat cycles, change to coal-firing, and more efficient auxiliary drives.

Diesel propulsion is used extensively in the world fleet-diesels power over 90 percent of the world's merchant ships. Recent interest by U.S. operators and Government agencies in diesel propulsion has led to the licensing and construction of slow-speed diesel engines in this country. The American President Lines (APL) new C-9 class containership, the *President Lincoln*, represents the first diesel-powered containership to be constructed in the United States. APL has constructed three C-9S. With a gross registered tonnage (grt) of 40,500 each, they are the largest in this country. The total container capacity is 2,500 teu which includes accommodation of 400 refrigerated 40-ft containers. The slow-speed two-stroke engines are Sulzer Brothers Ltd., designed and licensed for construction by Allis Chalmers Co. in the United States. They are the first such engines constructed in this country in the past 30 years. Changes in MarAd regulatory requirements were necessary to allow construction of the engines with a high percentage of foreign manufacturer components.

Diesel engines are the most efficient prime mover available in mass production in the size ranges required for main propulsion plants. The diesel industry has a long history of improvements in the performance and power ratings of their engines. In recent years, the ability to burn heavy fuels was developed for the low-speed engines which gave them an economic advantage over steam turbine plants. This experience has been extended to the medium-speed diesels although typically with somewhat lighter fuel characteristics. Since the fuel crisis of the mid- 1970's, the efforts to use less expensive fuels and to recover waste heat to the greatest extent have been intensified.

Diesel engine manufacturers have worked toward raising the mean-effective-cylinder pressure (mep), together with improved designs for turbocharging, to improve both the efficiency of the engine and the power rating of each cylinder. Parallel efforts have been made to protect the engine from the products of combustion with heavy, dirty, and corrosive fuels. Very recently, several major engine builders and research organizations have experimented with firing pulverized coal as an injected slurry. The results of tests to date have been encouraging. Typical slurries have been 68 percent oil and 32 percent coal by weight and 66 percent water with 34 percent coal by weight. Synthetic fuels, derived from coal, also can be used as diesel fuels.

Alternate Fuels

Currently, the merchant fleet consumption of bunker fuels amounts to 3 percent of the world petroleum supply.[13] Bunker fuel sold in 1981 totaled 730 million barrels at an average cost of $32 each. Current prices are dropping rapidly along with crude reductions below $30 per barrel. Marine consumers represent a large single user of petroleum products but not enough to affect the mix of fuel products produced by the world's refineries. In general, the mix of distillate and residual products refined by the oil industry is dictated by consumer and industrial demand for gasoline and light distillate-fuel oils. The marine, utility, and asphalt industries consume the remaining residual-oil products. The properties of residual oils have been deteriorating in recent years due to the improved efficiency of new refineries. A greater percentage

[13] L. Bergeson, et al., "Wind Propulsion for Ships of the American Merchant Marine, " Wind Ship Development Corp., U.S. Maritime Administration Report No. MA-RD-940-81034, NTIS No. PB-81-162455, March 1981.

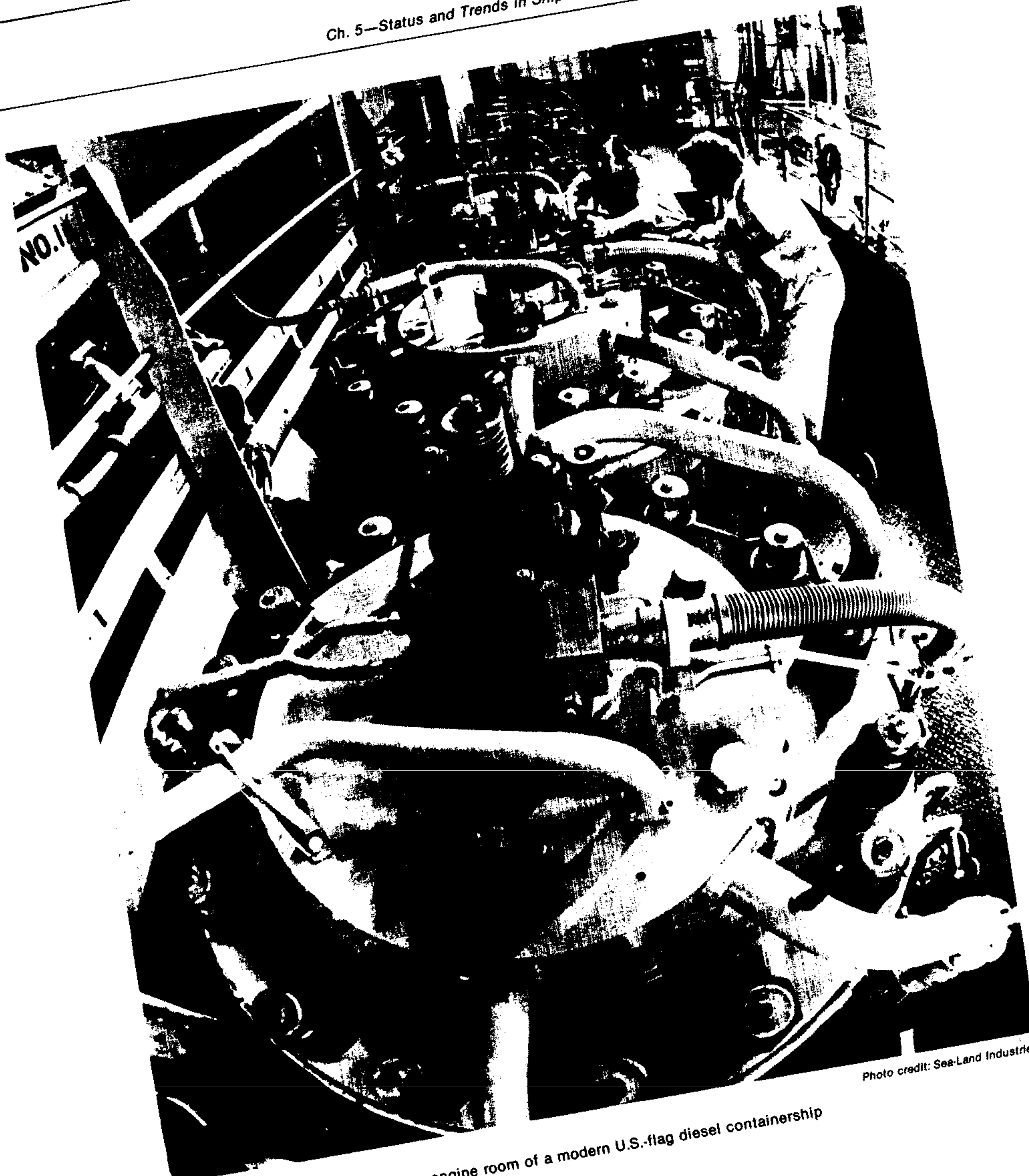

Photo credit: Sea-Land Industries

The engine room of a modern U.S.-flag diesel containership of distillate-oil products is now produced from each barrel of crude oil.

Since the oil embargo of 1973 there has been a gradual shift from oil firing back to coal in land-based steam utility boilers. This increased utilization of coal will increase demand for worldwide coal transportaton. Coal remains an outstanding resource, with about six times the proven world reserves of crude oil. As a result, an increase in coal shipping seems assured during the next century. If U.S. coal exports grow as most experts project, new bulk carriers will enter that trade. These ships also could burn their cargo as fuel. Advanced technology for handling and burning coal now is being developed. For example, research in fluidized bed combustion and the use of micro-coal slurries for firing piston engines is well underway.

Coal-fired ships only recently are being reintroduced in a few bulk trades. General Dynamics Corp. shipyard at Quincy, Mass., delivered a 36,000-ton coal-fired coastal collier in July 1983 for New England Electric. This ship is the first coal-burning vessel built in the United States in over 30 years and is projected to offer considerable savings to the utilities that transport coal from Norfolk to New England powerplants. Mitsubishi's Nagasaki shipyard completed the first of a series of two coal-fired bulk-carriers in September 1982 for Australian National Line (ANL). Two additional coal-fired bulk-carriers will be constructed in Italy for TNT Bulk Ships, another Australian operator. All four ships are chartered to carry bauxite ore, The ships' main boilers are twin, U.S.-designed, Combustion Engineering Co. boilers licensed for construction by Mitsubishi. All coal-handling operations from transfer to ash disposal as well as boiler combustion control are automated or remotely controlled in accordance with recommendations issued by Lloyds Register of Shipping. ANL currently es-

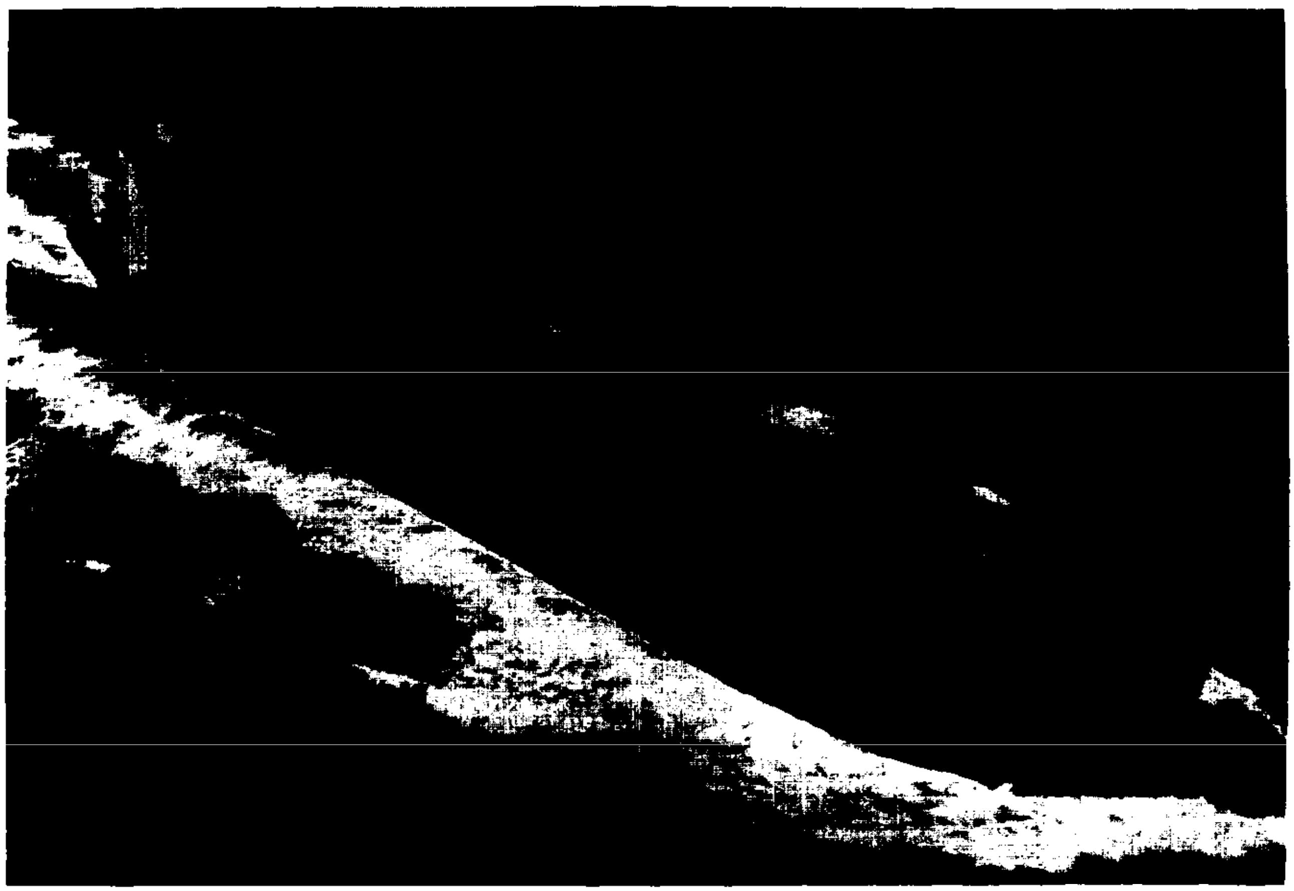

Photo credit: General Dynamics, Inc.

In 1983 this U.S.-flag coastal coal-carrier was built to use its own cargo as fuel

timates an annual savings of $1.3 million from operation of these vessels. The company indicates coal prices would have to double relative to heavy fuel oil for operating cost parity. In addition, two former LNG tankers were converted to grain carriers with coal-fired boilers at a Korean shipyard for U.S. owners.

Nuclear-fueled steam plants have been installed in oceangoing vessels for several decades. The largest number of nuclear vessels are naval submarines. A small number of nuclear-powered merchant vessels have put to sea during the past several decades. The technology of these vessels has improved gradually. Most experts agree that, based on the price of oil, they are not yet economically competitive with their fossil fuel-fired counterparts. Other obstacles have hampered the development of nuclear ships, including the issue of disposition of spent nuclear fuel. In addition, there is significant popular opposition to the entry of nuclear-powered ships into major world ports.

Research has been intensive during the past decade in alternative fuel sources due to the expected crude oil shortfalls. A range of synthetically produced fuels from coal have long-term development potential. Likewise, natural gas vented from oilfields has not been competitive due to uneconomical transportation costs. Reserves of shale and tar sands represent about 13 percent of all fuels but are considerably more expensive to extract. As supplies of crude oil tighten and the price rises, producing competitive alternate fuels will become more feasible. The recent drop in crude oil prices may cause interest in alternative fuel for marine propulsion to wane.

Advanced Powerplants

The declining availability of liquid fossil fuels may provide long-term incentives for changing to new advanced powerplants. A recent MarAd study identified several advanced powerplants with development potential for marine applications. 14 Each was found to be potentially compatible with future marine plant requirements and to be economically competitive with the best existing technology. A crucial factor was freedom from the use of crude oil-derived fossil fuels. After screening several dozen options, the following plant types were selected for ' 'long-term' development potential:

- machinery plants under development that burn solid (coke and coal) slurry fuels include two-stroke marine diesels, fluidized-bed boilers for steam plants, Stirling cycle reciprocating engines, closed Brayton cycle gas turbines;
- lightweight nuclear powerplants in the near term using light-water reactors and high-temperature gas-cooled reactors beyond; and
- fuel cells.

The suitability of those advanced powerplants is directly related to the type of ship considered for their application. Representative hull forms were tested for applicability. The advanced powerplants that show a potential advantage were compared against one another and against the projected development of present-day powerplants. The results of the study indicated that fuel consumption rates of advanced plants are not likely to be significantly better than the current performance of low- and medium-speed diesel engines. Their only advantage is the ability to burn alternative fuels.

Propulsor Technology

While a few other special-purpose propulsor devices are used occasionally on merchant vessels, the screw propeller is accepted universally as the most efficient and cost-effective propulsor that can be used with any type of powerplant. Over several hundred years of development, the capabilities and limitations of the screw propeller have been thoroughly analyzed and are well understood. When the ship hull is defined, the powerplant selected, and the operating conditions are known, the optimum propeller for the ship can be designed.

This is not to say that all ships are operated at their maximum propulsion efficiency. Constraints imposed by hull form, powerplant characteristics, variable trim or displacement, or variation in speed requirements may compromise the propeller design to the point where its efficiency is much lower than what might otherwise be realized. An explanation of the effect of some of these factors on propulsor performance, and the means of circumventing some of the problems, are described below.

[14] 'Merchant Vessel Advanced Power Systems, Maritime Administration, U S Department of Transportation, contract No. MA-80 - SAC-01072, prepared by The Baham Corp., Columbia, Md., January 1982.

To carry the maximum cargo within a given length, beam, and draft, it is often the practice to design a ship hull that has very full stern lines. These in turn interfere with the flow to the propeller and create a very high wake. This means that the inflow to the propeller is restricted, reducing propulsive efficiency. The situation can be improved by converting to large-diameter propellers that capture more of the flow around the hull or by using wake-adapting nozzles or ducts that selectively accelerate the flow from the ship sides and bottom into the propeller where it can be utilized more efficiently.

The characteristics of marine powerplants have much to do with propulsive efficiency. Steam reciprocating engines and steam turbines are uniquely applicable to the torque demands of a screw propeller at a given RPM. In other words, there is a relatively flexible relationship between the torque and RPM of a steam engine that can adapt it to the torque-RPM demands of a screw propeller. This gives the propeller designer a bit more leeway in keeping the design in an efficient range. However, as cited earlier, the higher fuel consumption and costs of steam-powered propulsion systems tend to more than offset this design advantage.

A diesel drive, on the other hand, requires a much more precise matching of the propeller power demand with the engine output capability. Care must be exercised that the propelter torque demand does not exceed the engine torque supply before the engine gets up to speed. Thus, the designer's tendency is to design the propeller on the low-torque side of the maximum efficiency curve to stay out of trouble; as a result, the propeller may not be of optimum efficiency.

As a general rule, the efficiency of a screw propeller can be improved by increasing the propeller diameter and decreasing the propeller RPM, Obvious limitations on diameter are the cross-section dimensions of the ship's hull, the need for adequate tip clearance, and the desire not to have the propeller swing below the keel line. The low-RPM limitation is a function of minimum speed of main propulsion engines and the size of reduction gears required. As engine RPM decreases and reduction gear size increases, there is a point of diminishing cost effectiveness in improving propeller efficiency with large-diameter, slow-turning propellers. The overall weight of the propulsion system is also a serious consideration in selecting propellers.

There are also several alternatives to increasing the diameter of a propeller. Various forms of ducted propellers can be used since, with a flow-accelerating nozzle surrounding the propeller, the thrust load is divided between the propeller and the nozzle with the nozzle delivering up to one-half of the total thrust under certain conditions. Also, a propeller in a nozzle can turn at a higher RPM than an equivalent open screw, alleviating the problem of lowering the rotational speed to impractical rates.

Another alternative that can be used to reduce propeller blade loading is to employ tandem or contrarotating propellers. In these units, the forward propeller gives an initial acceleration to the flow, and the after propeller provides additional acceleration with the result that neither propeller is as heavily loaded as would be a single propeller under the same circumstances. The after contrarotating propeller also can recover additional energy from the tangential outflow of the forward propeller, giving this system a higher propeller efficiency than the tandem propeller for corresponding size and hydrodynamic conditions.

Each of these additional techniques for improving propulsive efficiency has certain drawbacks. Propellers in nozzles are subject to problems, and the cost of' acquisition, installation, and adequate support of a duct with the required small tip clearance is high. However, some of these drawbacks are ameliorated in the Mitsui integrated-ducted propeller where the nozzle is placed aft of the propeller. Tandem propellers involve the additional cost of the second propeller. Moreover, the extra aperture length and shaft support augment the design difficulties and installation and repair problems. Despite the fact that contrarotating propellers have been used since the 1830's and are known to give a significant increase in propeller efficiency, the mechanical difficulties of turning propellers on concentric shafts in opposite directions and the associated high installation and maintenance cost have deterred ship operators.

One promising method of increasing propulsive efficiency is the use of vanes forward and after the propeller to convert the tangential flow generated by the propeller into forward thrust. This technique was patented by the Goldschmidt Corp. in the 1930's and called the "contrapropeller" or "contrarudder.

The contrarudder principle was used in the early Maritime Commission ships (during World War II) and, on a model test of a C3 cargo-ship hull, a propulsive efficiency increase of 15 percent was demonstrated over that obtainable with the then customary flat-plate rudder. Such significant improvements cannot be anticipated with modern rudder-foil configurations, but Mitsubishi has reported power savings of up to 7 percent with similar modifications to the stern and rudder that now are being called ' 'reaction fins. This appears to be a promising propulsor system modification that can attain demonstrated fuel savings at a modest initial investment and no additional operating costs.

Sail Propulsion

Ocean winds have been a traditional source for ship propulsion for the past several millenia. Historically, trade routes and shipping patterns were designed to be compatible with seasonal wind and current patterns. With the advent of mechanical propulsion, there developed a tendency to ignore weather in setting routes and schedules. But, over the past 25 years, ship operators have come to recognize the savings made possible by routing their vessels to avoid adverse weather and to use favorable currents. Advances in satellite weather observation and computerized prediction techniques have made weather routing practical.

In the past few years, proposals have been made to employ wind energy as the means for propelling small- to moderate-sized oceangoing ships, either as the sole means of propulsion or as a supplementary form of thrust to reduce the required main engine output. The most suitable applications appear to be for smaller vessels, particularly those operating on an open schedule. Economic assessments of modern sail installations have been made both as a retrofit to an existing ship and on a new ship designed for sails. The proposals presented to date are quite varied, and several small ships have been fitted out with modern sails for evaluation in service. Most proposed applications are for small motorships of 500 to 4,000 dwt. To minimize the hazards to personnel, and the manning and maintenance costs of traditional rigging, these proposals generally are based on power-operated devices with remote controls for setting and furling sails,

It appears that modern sail arrangements are feasible for some types of cargo ships as a supplementary means of propulsion. Evaluations would have to be done on the type of sail, the vessel, and the operating route. A study was conducted by MarAd and published under the title "Wind Propulsion for Ships of the American Merchant Marine. The results of the MarAd study, conducted by Wind Ship Corp., indicate the cost of sail-assisted motorships to be competitive with conventional motorships and predicted that they would consume 18 to 25 percent less fuel. The Japanese built a 1,600-dwt sail-assisted motorship in 1980 and have been operating it as a pilot project since then. They claim similar fuel savings as Wind Ship Corp. Wind Ship also operated a converted small freighter in Caribbean trades which has a sail added for supplementary propulsion and fuel reduction. These projects, while limited in scope and at an early stage, do provide valuable data about the feasibility of future applications of sail power for merchant shipping.

TECHNOLOGICAL INNOVATION IN SHIP OPERATIONS

There is a strong perception on the part of many in the maritime industry that the noncompetitive nature of the U.S. merchant marine is due to a gradual increase in the cost of U.S. ship operations relative to foreign ship operations. Likewise, this noncompetitiveness is often associated with the belief that technological innovation has not resulted in implementation of new concepts into the U. S.-flag fleet.

To address this question, OTA sent a questionnaire to members of SNAME'S Ship Technical Operations Committee.[15] The following summarizes the opinion of those responding to each of the four questions. * While the responses differed on many points, there were important areas of agreement.

Question 1:

How do the U.S.-flag, U.S.-owned and foreign-owned, foreign-flag fleets compare in technological advancement, including automation, fuel efficiency, propulsion, cargo specialization, or others that you consider important?

Two-thirds expressed the concern that the overall technological advancement of U.S.-flag fleets lagged behind foreign competitors. Two made the point that recent U.S. construction has tended to incorporate a significant amount of new technology. One insisted that U.S. innovation is on a par with the rest of the world, and that "the popularly perceived deficiencies in U.S.-flag, U.S.-owned fleets are not technological in nature, but institutional and economic.

All agreed that with respect to fuel efficiency and the introduction of diesel engines, the United States has lagged considerably. Various reasons were given including lack of available diesel engine industry "infrastructure, low fuel cost (prior to the 1973 embargo) for steamplants, and insufficient research facilities and expenditures.

Automation in U.S.-flag fleets generally was conceded to be inferior to foreign-flag, foreign-owned fleets. Most U.S.-flag ships are not certified for unattended engineroom operation. The reasons put forward were basically that it is difficult to automate steam-propulsion systems and that operators have no incentive to do so because prevailing labor agreements do not allow removing watchstanders.

Cargo specialization is another area in which U.S.-flag ships generally lag foreign competitors. Those innovations that have been developed in this country have long since been replicated by foreign competitors. A telling example was cited in the case of containerized liner cargo. A U.S. operator pioneered the concept over two decades ago. The U.S. liner operators are generally conceded to be the healthiest segment of industry. However, today the U.S. liner fleet is less containerized overall than its major European and Far East competitors. The United States has not participated in cargo specialization developments, particularly in the bulk and specialty trades. The one exception mentioned is in the area of product tankers. The extensive importation and coastwise shipping of refined crude oil products have resulted in refined practices being developed for these ships by U.S. fleet operators.

Question 2:

What new technologies are most likely to be incorporated in the fleets over the next 20 years and will have a major impact on how future ships are designed, built, and operated?

The overwhelming opinion of the respondents was that technological resources in the shipping industry would concentrate on reducing operating costs with the cost of manning and fuel of most concern. The largest number of respondents, identified the need for automation technology to be implemented to reduce manning requirements on U.S.-flag ships. Crew costs are high on U.S. ships because crew sizes are larger than competitors and cost per man is among the highest in the world. They cited several areas where microprocessor technology could be applied with a minimum of development effort. These included reducing onboard administrative burden, satellite navigation, weather routing, and cargo management. With automation

[15] 'Assessment of Maritime Trade and Technology, questionnaire for SNAME Ship Technical Operations Committee, for the U.S. Congress, Office of Technology Assessment, October 1982.

*Responses to footnote 15: Matson Navigation Co., A. J. Haskell, Jan. 27, 1983; Reomar, Inc., N. M. Miller, Feb. 11, 1983; Sun Refining & Marketing Co., Joseph D. Mazzei, Feb. 11, 1983; Society of Naval Architects and Marine Engineers, James J. Sweeney, Chairman, SNAME Panel O-21, Feb. 14, 1983; Energy Transportation Corp., E. G. Tornay, Feb. 14, 1983; Exxon Shipping Co., T. W, Gillette, Feb. 25, 1983; Mobil Oil Corp., J. V. Caffrey, Mar, 3, 1983; Chevron Shipping Co., W. H. Banks, Mar, 3, 1983; E. V. Lewis (formerly Webb Institute Director of Research), Mar. 12, 1983; Marine Transport Lines, Inc., Donald V. Horn, Mar. 2, 1983; U.S. Lines, Inc., William B. Bru, Apr. 21, 1983; Delta Line, Richard F. Andino, Apr. 4, 1983; Cushing & Co., C. R. Cushing, Jan, 11, 1983, technology currently available and implementation of new training, maintenance, and administrative procedures, crew size could be reduced to 20. With the technology that will be introduced in the next decade, it will be possible to reduce crew size to 10 on diesel-powered ships, and, in the long term, no personnel will be required onboard for normal operations. However, several respondents noted that even if these latter options could be negotiated with labor unions and regulatory bodies concerned with vessel safety, it would not necessarily be the most economical way to operate. An optimum balance must be derived that takes into account not only the technological implications but also the economics of ship acquisition, manpower costs, and safety considerations.

Eight respondents noted that phasing-out steam turbine, high-speed diesel, and gas turbine propulsion in favor of medium- and low-speed diesel engines for most ship designs is a likely trend. As long as oil remains the primary marine fuel, diesel engines will predominate as the most efficient propulsion system. Decreased availability of oil and high prices relative to other energy sources will favor development of other engines. The only near-term alternative for large ships is steamplants using coal-fired boilers. Coal is not readily available at all major ports. Thus, its use is likely to be limited by fuel supplies. Five respondents predicted the return of coal-fired ships, particularly for bulkships hauling coal. Twenty-five percent of the respondents identified nuclear propulsion as the most likely long-term development beyond the next two decades.

As mentioned earlier, fuel consumption is one of the major cost factors that shipping companies will target for reduction. More than half of the respondents identified improved hull-form design and acceptance of ablative (self-polishing) antifouling hull coatings as a continuing trend. Optimum speed of inservice vessels, particularly for bulk trades, will continue to reduce. There will be a continued trend to larger hull sizes for most high-volume trades except tankers, which have peaked in tonnage. Cargo specialization such as containerization, RO/RO ships, and automobile carriers will cross-over increasingly into the bulk trades. Although LNG technology was introduced prematurely, it most likely will be viable over the long term. Icebreaking tankers will be required for *arctic* shipment of crude oil. Finally, 25 percent of the respondents identified cargo-handling and port-facility improvements for reduction of loading time as an area of continuing improvement.

There were a number of additional elements of ship operations identified by less than half of the questionnaire respondents that affect operating costs. They include the hydrodynamic efficiency of the propeller, power losses associated with appendages, and the mechanical efficiency of the main propulsion system as well as hotel services for the crew. About 25 percent of the respondents identified these areas for selected improvements.

Question 3:

> What technological innovations in operation of ships and shipping systems are most important for future U.S. shipping? (i. e., where U.S. shipping conditions are unique or where opportunities exist for the United States to take the lead).

There were five respondents who expressed the opinion that the U.S. Government and shipping industry should concentrate on crew organization, training, laws, and regulations that affect operating cost. Specific recommendations included making substantial changes in maritime law and manning regulations to delete the three-watch requirement and allow cross-training of trades, particularly deck and machinery. In the area of industry practices, it was mentioned that rationalization of galley/messing practices that would lead to use of a *single* mess-space, preplanned meals, or perhaps self-service would yield savings.

Twenty-five percent of the respondents indicated they felt the area of greatest ' 'business opportunity' for U.S. technology was the application of computers to every facet of the shipping industry. Rapid assimilation of computers into shipping operations would give U.S. companies a competitive edge,

Similarly, 25 percent of the respondents identified opportunities in the specialty trades that would have a high payoff for U.S. companies. In the liner trades, encouragement of laws and regulations favoring intermodal shipping would be most beneficial in giving U.S. companies a boost. In the bulk trades, "neobulk' shipping of commodities such

Photo credit: Atlent/c Rlchfleld, Inc.

Computers such as this one for satellite communications are commonly used aboard modern merchant ships for automation of many tasks

as vehicles, forest products, and refrigerated cargo represents a large area of trade in which U.S. shipping companies have almost no presence. Export of perishables and grain should be high on the opportunity list. One respondent suggested that the presence of a U.S. cruise ship operator in the Caribbean trade would be desirable.

Question 4:
What Federal policies and programs have a significant effect in encouraging or inhibiting technological innovations in U. S. shipping?

The opinion of half the respondents was that, in general, substantive, long-term changes are required in U.S. maritime policies affecting the shipping industry. However, there was no agreement on what these policy changes should be. Policies that tend to reduce the size of the U.S.-flag fleet also will tend to retard innovation. Long-term stability also was mentioned as being needed for reducing the risk for new investment. The current rapidly changing policy environment creates uncertainty.

Four respondents indicated that ship construction and operating subsidies have impeded innovation and investment in U.S. shipping during the past several decades. Either removal or restructuring the subsidy programs to encourage investment of new ships was recommended.

Three respondents noted the following areas of concern:

- "buy America" provisions for building and repairing ships are considered excessive Government intervention;
- U.S. Coast Guard (USCG) regulations are unnecessarily restrictive, particularly where they exceed international standards;
- labor policy should be directed toward reduction of U.S. manning and watchstanding requirements; and
- MarAd R&D programs should be directed toward industry cooperative efforts with "front-line' shipping organizations rather than consulting firms and academic institutions. In general, the level of research activity should be increased.

MARITIME R&D

The majority of direct Federal Maritime R&D support his been provided by MarAd, augmented by support from USCG for work falling within its jurisdiction. U.S. Navy R&D frequently benefits the maritime industry as a whole, and thus the U.S. Navy program is watched carefully for fallout that will benefit the merchant marine. As one example of cooperative effort that has been in effect since World War II, the NAS Ship Structures Committee is supported jointly by MarAd, USCG, the

Naval Sea Systems Command, the Military Sealift Command (MSC), and the American Bureau of Shipping (ABS).

MarAd R&D Program

Most federally sponsored R&D that is applicable to merchant ship design, construction, and operation is that currently funded by the MarAd R&D program.

The relative costs of the various aspects of MarAd R&D are indicated in table 38, listing fiscal year 1982 procurements as percentages of the $14.45 million total.

These funds include both cost-shared projects and projects that are interagency reimbursable. It can be seen that shipbuilding research, cargo-handling, and CAORF* account for two-thirds of the total budget with all other areas of R&D making up the remainder. A brief examination of the R&D results is contained in the paragraphs below.

[16] 'Research and Development Program Briefing, " Maritime Administration, U.S. Department of Transportation, Jan. 27, 1983.

*CAORF is a ship's bridge, harbor, and navigation systems computer-assisted simulator, located at MarAd's Kings Point, N.Y. facility. It is used to study ship control, navigation, and maneuvering and new devices for safe operations. It also is used for operational training.

Table 38.—Relative Costs of Maritime Administration R&D (fiscal year 1982)

Research area	Percent total
Shipbuilding research	26.09
Ship machinery	6.25
Fleet management	5.83
Ship performance and safety	3.07
Cargo-handling	12.58
University research	1.72
Structures (ship structure committee)	0.24
Arctic technology	2.50
Marine science	1.95
Navigation/communication	6.54
Advanced ship systems	1.69
Computer assisted operations research facility (CAORF)	28.59
Port and intermodal development	1.81
Market analysis	1.16

SOURCE: US. Maritime Administration, 1983

The National Shipbuilding Research Program

The shipbuilding productivity aspect of the MarAd program is essentially the National Shipbuilding Research Program (NSRP) being carried out with joint sponsorship of SNAME and a number of shipyards and other members of the maritime industry. This program is considered effective by most participants, and the joint industry/Government cost-sharing approach has been cited as a mechanism that assures resources are applied to the most pressing problems.

The program currently is conducted on a cost-sharing basis with four major shipyards: Todd Pacific Shipyard, Avondale Shipyards, Inc., Bath Iron Works, and Newport News Shipbuilding. Todd is working on improved outfit and production aids. Avondale is working on improved surface preparation and coating and the feasibility of incorporating process lanes in U.S. shipyards. Bath is developing shipbuilding standards and improved production methods, and Newport News is working on design/production integration methods and on welding productivity and quality. This program was instituted in 1973 by the Ship Production Committee (SPC) of SNAME, the cooperating shipyards, and MarAd. Some important advances in ship production technology have resulted.

One element of the program involved setting up the Institute for Research and Engineering Automation and Productivity in Shipbuilding (IREAPS). IREAPS is a not-for-profit organization of shipbuilders and other members of the maritime industry set up to facilitate contracting procedures and the dissemination of information resulting from NSRP.

The SPC and IREAPS have prepared "The Five-Year National Shipbuilding Productivity Improvement Plan (1983 -1988 [17] This plan was prepared under the guidance of a steering commit-

[17] "The Five-Year-National Shipbuilding Productivity Improvement Plan (1983 -1988)," prepared by the Ship Production Committee and the Institute for Research and Engineering for Automation and Productivity in Shipbuilding, March 1983.

tee composed of nationally recognized experts in the field of shipbuilding, including members from both Government and industry. Seven task groups participated in the preparation of this plan. The plan contains a large variety of proposals for shipbuilding research projects. The authors claim that it details a strategy for restoring the U.S. shipbuilding industry to a position of worldwide leadership, the structure of an implementing organization, a methodology for project development and screening, a means of measuring project performance, suggested sources of funds and a funding plan, and a procedure for plan review and adjustment.

The plan appears to provide a reasonable approach to many aspects of productivity research. Such research could contribute to a more productive and profitable shipbuilding industry in the United States.

Cargo Handling

The MarAd cargo-handling program is devoted mostly to the development, testing, and evaluation of techniques and equipment for handling and stowing military equipment aboard containerships. Fifty-one percent of the financing is provided by the U.S. Navy. Results so far have been the design and fabrication of very large transport units for a project called "Sea Sheds' that will permit containerships to carry a full range of military vehicles and equipment. Crane installations aboard containerships for handling Sea Sheds also are being studied. A significant portion of this work is financed by the U.S. Navy, and it is directed toward U.S. Navy problems.

CAORF

The operation of MarAd's CAORF, which is principally the bridge simulator with associated equipment, consumes a larger percentage of the MarAd R&D budget than the expenditures figure indicates. Of the 1982 total of $4.13 million spent on CAORF, $2.61 million was for operation, maintenance, and engineering support; only $142,000 was expended directly for outside agency project work. The remainder presumably was used for MarAd project work, although the output from this remaining $1.38 million expenditure is not readily identifiable in MarAd program summaries. The output of this facility has not been evaluated adequately. Its cost appears to exceed the importance of this type of research relative to the overall MarAd program.

CAORF has absorbed a major part of MarAd R&D program funds over the last several years. Despite the fact that the construction of this facility was based on conducting research work, its primary use has been for training that might have been accomplished more economically by other means.

U.S. Navy R&D Related to the Merchant Marine

There are a number of areas where the work being done by the U.S. Navy is directly applicable to merchant work. It is assumed that U.S. Navy R&D will continue to be funded adequately. So long as there are no security problems involved, it is important that those efforts that produce results of value to the maritime industry are made available to the industry.

Ship hydrodynamics encompasses hull-form configuration for minimum resistance and maximum seaworthiness, frictional resistance of the hull, propulsion system performance, interaction between propeller and hull, performance of maneuvering system elements (including rudders and maneuvering propulsion devices), performance of bilge keels and other antiroll devices, and hydrodynamically induced noise and vibration. The U.S. Navy has active R&D in all of these areas, including both inhouse R&D and contract work under the General Hydromechanics Research Program. 18 The results of these programs are generally applicable to merchant ships and, except for a few programs related to hydrodynamic noise, most results are available directly to the maritime industry through reports.

The only hydrodynamic research probably required on merchant ships that is not covered by U.S. Navy programs is that related to inshore maneuvering and docking in rivers and harbors, particularly of large-beam, shallow-draft vessels. However, there is research on ship mooring loadings sponsored primarily by the Naval Facilities Engi-

[18] "General Hydromechanics Research Program, " fiscal year 1983, Ship Performance Department, David W. Taylor Naval Ship Research and Development Center.

neering Command, and the results of work in this field are equally applicable to both naval vessels and merchant ships, In fact, the U.S. Navy has a specific interest in merchant ships that are moored for long periods at advanced base locations as part of the Rapid Deployment Forces supply system. [19]

Navy structures research that is related to merchant ships is carried out primarily by the NAS Structures Committee, which the U.S. Navy sponsors through both the Naval Sea Systems Command and the MSC. Other research on ship structures carried out by the U.S. Navy in its own laboratories and under contract is devoted generally to studies of special materials or to structures subjected to high-submergence pressures. This latter work is not of any particular interest in merchant ship construction.

Shipbuilding productivity is of as much interest in the construction of naval vessels as in the construction of merchant vessels. The U.S. Navy has supported the joint SNAME/MarAd/Industry programs and also has encouraged private shipyards to incorporate high-productivity techniques in naval construction. Several technological advances in this area have been attained on military construction projects. [20] Many yards have adopted computer-aided design and manufacturing (CAD/CAM) systems in some portion of their operations. Several yards have begun implementing zone construction and outfitting techniques, in some cases utilizing Japanese consultants to evaluate the most suitable process. Since the U.S. Navy is now, and for the near future will continue to be, the principal customer for U.S. shipyards, productivity improvements here are most important to reduce the cost of military ships.

Computer-Aided Design and Manufacture

The term CAD/CAM is commonly used to refer broadly to the use of computers in industrial design and manufacturing. Currently the most sophisticated systems are "integrated information systems' that encompass product definition as well as engineering and manufacturing configuration control. It is recognized now that a key factor in the successful utilization of CAD/CAM technology is developing a product definition database with the ability to communicate with other information systems. During the past decade, MarAd and the U.S. Navy have been promoting the transfer of this technology into the shipbuilding industry. Directly and indirectly as a result of these efforts, a variety of incompatible software systems have been instituted and now must be integrated.

A recent study conducted for the U.S. Navy by the National Research Council (NRC) found that new applications of CAD/CAM in the last decade have resulted in applications over a broad range of industries internationally. Over 25,000 workstations are in use worldwide in all industries today. The Navy Shipbuilding Technology Committee of NRC concluded that less than 500 CAD/CAM workstations are in use by the U.S. Navy and shipbuilders in the United States currently. The major findings of the committee were:

- Navy and MarAd support for NSRP should be continued;
- the productivity of the U.S. shipbuilding industry for commercial vessels is one-half that of foreign competitors. Naval vessel construction productivity was not evaluated; and
- CAD/CAM applications in U.S. shipyards have resulted in reductions in fitting and welding costs to date. The U.S. Navy is in a good position to resolve CAD/CAM issues to foster its rapid application in shipbuilding in conjunction with the industry.

The NRC study specifically recommends CAD/CAM technology as a method for improving the relative productivity of shipbuilding design and production. Computer hardware and software companies in the United States have developed state-of-the-art CAD systems that have an important share of the world market. U.S. commercial yards utilize this technology to some extent. NRC esti-

[19] "Forces and Moments on Ships To Be Moored at Diego Garcia," prepared by Robert Taggart, RT-4 1401, submitted to Chesapeake Division, Ocean Engineering and Construction Project Office, Naval Facilities Engineering Command, July 1980.

[20] "Shipbuilding Productivity: Something is Being Done, discussion by Peter E. Jaquith, Bath Iron Works, panel discussion at the joint ASNE, Flagship/SNAM E, Chesapeake Section meeting on Jan. 18, 1983

[21] 'Productivity Improvements in U.S Naval Shipbuilding, " Committee on Navy Shipbuilding Technology, Marine Board Commission on Engineering and 'ITechnical Systems, National Research Council, Nat ional Academy Press, Washington, D, C,, 1982.

mates that 1 to 5 percent of shipbuilder design and drafting tasks are conducted with CAD assistance. Additional tasks can be incorporated in the future when database information necessary to utilize the CAD system potential becomes available.

The U.S. Navy, both inhouse and through design agents, creates thousands of drawings and design reports when designing a ship and establishing its specifications. These are then passed to the contracted shipbuilder in paper form as a design information package. The same hull geometry is redrawn and manipulated by many engineers and designers in different organizations prior to shipbuilder preparation of production plans. The shipbuilder then manually reviews the design paperwork to complete material and equipment ordering, develop schedules, and other activities. To date, computers have been used for such design calculations as preparing hydrostatic curves, powering and stability analysis, longitudinal strength calculations, structural design, and structural finite-element analysis.

The use of integrated CAD/CAM has not been implemented fully in the world shipbuilding industry. However, according to a report prepared by A & P Appledore, Ltd., for this study, the European, Japanese, and Korean yards are considerably more advanced than U.S. shipyards at the present time.[22] The Appledore report concludes "a necessary adjunct of installing CAD/CAM is that all design and drawing offices and the loft (shipyard layout functions) must be brought together. " While shipbuilding shares many design and construction requirements with other production industries, it has three unique features. They are:

- the use of a single set of technical and production resources with overlapping contract cycles. The products of a typical production line often are quite different from one project to the next. Completely standard ships and series production are more the exception than the rule;
- the large variety of hull-surface geometries that must be matched with hull-volume and payload constraints; and
- the amount of data required to generate an accurate definition of the spatial geometry of the hull and its stiffening structure and foundations is very large compared to other industries.

The potential benefit of CAD/CAM technology to the shipbuilding industry is improving productivity by reducing the direct labor contribution and facilitating coordination of management and engineering functions during the shipyard production phases. Reliance on the traditional paper mode of product description produces a slow rate of information flow. Tighter schedules and increased control of production results from increased information flow. Real productivity improvements can be realized from more efficient planning, scheduling, and sequencing of the work processes of manufacturing, inspection, and testing of the ships' subassemblies.

CAM packages have been developed in a number of countries (including most West European shipbuilding countries, Japan, and the People's Republic of China), but with initial use in their domestic yards only.

Now, however, a number of them are being exported. AUTOKON (from Norway) and FORAN (from Spain) have the highest export sales. Japan has actively promoted the export of their shipbuilding technology abroad. A Japanese shipbuilder, Ishi Kawajima, Harima Heavy Industries Co. (IHI), is under contract to Avondale Shipyard and Bath Iron Works. Several U.S. yards have acquired versions of the Norwegian AUTOKON system as well as a number of additional systems. Examples of systems used by U.S. yards are:

Avondale:
- CADAM (drafting system) by Lockheed Corp.
- AUTOKON by SRS, Norway
- SPADES by Gali Associates, United States

Newport News:
- CADMAN by Lockheed Corp.
- AIDS (topological model) by Italcantieri, Italy
- AUTOKON by SRS, Norway
- AD 2000 (drafting system), by Newport News

Electric Boat:
- AUTOKC)N by SRS, Norway
- AIDS by Italcantieri
- CADDS 4 (drafting system) by Computer vision

Each shipyard now must integrate the variety of software they own; however, no U.S. shipyard has

[22] 'Technical and Capability Developments in Shipbuilding, prepared for the Office of Technology Assessment by A & P Appledore Ltd., Document No. OTA: OOO1, November 1982.

accomplished the necessary integration. Appledore, in its report to OTA, identified the importance of focusing on a broader range of database and software capabilities to obtain the full potential savings from CAD/CAM implementation. Increased productivity accrues from creation of one common database and then using it in several different shipbuilding applications such as lofting, weight estimating, vibration analysis, hull geometry, lines definition, material requirernents, and production management. Major U.S. companies in other industries such as General Electric Corp., Boeing Corp., and General Motors Inc. are committed to moving from product definition on paper to product definition in electronic form. Today the most sophisticated systems are part of integrated information systems that encompass product definition, engineering configuration control, manufacturing, purchasing, materials planning, quality assurance, and customer acceptance testing.[23] A system for shipbuilding would include the following typical modules:

- geometric design and manufacturing:
  - — steelwork geometry and hull-form generator,
  - —piping and electrical cable-routing system,
  - —accommodation design system;
- design analysis:
  - —naval architectural design analysis,
  - —finite-structural-element model-analysis package; and
- management information and control:
  - —material/drawing/work information database,
  - —contract management package (network analysis)
  - —purchasing and expediting system,
  - —man-hour recording and job scheduling system,
  - —material control system, and
  - —estimating and forecasting system

Technological Innovation

Technological innovations in ship production and ship operation do not necessarily stem from R&D programs such as those cited earlier. These innovations often are the result of an operator or design office observing a requirement or a potential market and evolving a design, selecting from available R&D results, to meet the need. This results in an innovation moving from the drawing board to shipyard production and into operation. Classic examples of this are the containership, LASH, Seabee, and the various seagoing tug-barge systems. Incorporation of technological innovations applies to subsystems as well as to total ship systems, e.g., the Ebel mechanical guy or split-vang cargo-handling gear, dockside container-handling systems, and bow thrusters for inshore maneuvering control .24 There seems to be no apparent reason why this trend will not continue to apply in the future as it has in the past.

This is not to say that R&D programs are not important but that they should be recognized for what they are. As an example, laser photogrammetry is a development resulting from the combination of research on lasers and research in the science of obtaining reliable three-dimensionial measurements from photographs. When laser photogram - metry is applied to the fabrication and precise mating of two hull sections in a shipyard, this becomes an innovation in ship production technology.

Federal Role in R&D

There is obviously some overall national need for maritime R&D. An important part of such research should be a continuing assessment of those areas where technological innovation can be applied to acquiring a greater share of the world maritime transportation market and a greater share of the world shipbuilding orders. Additionally, the R&D should include an ongoing evaluation of the work going on in marine and other fields (both U.S. and foreign) that can contribute to applicable technological innovation. This should be supplemented by programs to incorporate these innovations into design, production, and training programs that would lead to building and manning ships, as well as selling ships to other maritime powers to assure the United States an improved posture in world shipbuilding and ship operations. Both long-term

[23] 'Productivity Improvements in U.S. Naval Shipbuilding, " op. cit. , p. 47,

[24] "Inno\ation in the Maritime Industry, op. cit.

financial support and a research plan are needed to assure effective utilization of resources.

There are several basic problems associated with existing Federal maritime R&D programs. First, since there is no comprehensive policy defining the Federal role in maritime affairs, there also is no clear policy regarding the Federal role in maritime R&D. While the Federal approach to industry promotion has changed drastically in recent years, there appears to be little attention given to the resulting effect on R&D. The program now under the authority of MarAd has no clear focus nor set of long-range goals. This program is much too small to be expected to address in depth the broad range of technical problems in the maritime transportation business. Furthermore, there is no rationale for selection of a few projects as worthy of Federal support while others are left for industry or some other research enterprise. For example, the MarAd program is skewed toward supporting an expensive computer-aided ship-maneuvering-simulation facility that has several counterparts in industry. And, shipbuilding productivity research, while a good program, is difficult to justify as a MarAd effort when U.S. shipyards are building only military ships, and a major MarAd policy initiative is to promote foreign building of U.S. merchant ships.

For the future, it would be useful to define the Federal role in maritime R&D before additional funds are allocated and before a program is designed. As discussed in this chapter, near-term needs for energy-saving and automation technology are being addressed by numerous industries and private research groups worldwide. A broad range of new maritime technologies have been developed in a number of other countries and are readily adaptable. The U.S. Navy and other Federal agencies spend considerable funds on basic and applied maritime research problems, and applicable data can be transferred.

The future Federal role in maritime R&D should be based on a few overall principles:

- the Federal role in R&D should be a subset of an overall maritime policy;
- the Federal research effort should consider and exclude what U.S. industry can better do itself. There may be considerations of indirect incentives for industry R&D;
- the Federal effort should include methods of coordination and transfer of technology within the industry and from military, foreign, and other sources; and
- the Federal effort should focus on long-range problems and high-risk areas that are not addressed adequately by industry or elsewhere, the solution of which could contribute to overall national goals.