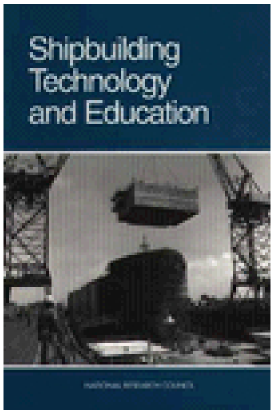

Shipbuilding Technology and Education

Committee on National Needs in Maritime Technology,
National Research Council

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Marine Board
Commission on Engineering and Technical Systems
National Research Council

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The following additional persons participated in the Workshop on the Role of Technology in Shipbuilding: Eugene Aspuru, Avondale Industries Inc.; Joseph A. Byrne, Maritime Administration; Stephen S. Clarey, National Steel & Shipbuilding Company; Tim J.V. Colton, Colton and Company; Andy Dallas, Advanced Research Projects Agency; Thomas H. Doussan, Avondale Industries Inc.; Roger Eshelman, Newport News Shipbuilding; Richard Goldbach, Metro Machine; Jon Grunning, Kockums Computer Systems AB, Sweden; H. T. Haller, Maritime Administration; Norman O. Hammer, Maritime Administration; Thomas W. Harrelson, Maritime Administration; Zelvin Levine, Maritime Administration; Thomas Lockwood, MARITECH; Phillip Nuss, Trinity Marine Group; Ellsworth Peterson, Peterson Builders Inc.; Bård Rasmussen, Kockums Computer Systems AB, Sweden; Todd Ripley, Maritime Administration.

The following persons participated in the workshop on Education in Naval Architecture: Michael Bernitsas, University of Michigan; Margaret D. Blum, Maritime Administration; David Billington, Princeton University, Board on Engineering Education; Francis M. Cagliari, Society of Naval Architects and Marine Engineers; James J. Conti, Webb Institute; Robert Holzman, U.S. Coast Guard; Robert Latorre, University of New Orleans; Peter Majumdar, Office of Naval Research; Joseph A. Schetz, Virginia Polytechnic Institute and State University; Frederick Seibold, Maritime Administration; Stephen E. Sharpe, U.S. Coast Guard; Ronald Yeung, University of California, Berkeley.

The following shipyard executives met with members of the committee: Albert L. Bossier, Jr., Thomas H. Doussan, Eugene J. Aspuru, Avondale Industries; Duane B. Fitzgerald, Gerard F. Lamb, Bath Iron Works Corporation; and Richard H. Voortman, Alfred W. Lutter, Jr., Stephen H. Streifer, National Steel and Shipbuilding Company.

Preface

The U.S. shipbuilding industry is at a turning point. Two decades ago the industry produced ships for both commercial and military markets. In the 1980s, the industry designed and built the world's most advanced naval capability in response to the U.S. Navy's goal of a 600-ship fleet. U.S. shipbuilders came to excel in producing complex, high-quality naval vessels. Yet commercial markets were left to foreign shipbuilders whose governments provided handsome subsidy support in the shipbuilding arena. Recently, dramatic declines in U.S. defense spending are forcing many large U.S. shipbuilders to translate their skills once again from military to commercial markets if they are to thrive or, in some cases, simply survive.

Congress and the Clinton administration have shown increasing concern about the industry's health as a matter of both military and economic security. In response to the National Defense Authorization Act of 1993, the administration developed "a comprehensive plan to enable and ensure that domestic shipyards can compete effectively in the international shipbuilding market." In this plan, *Strengthening America's Shipyards*, the president called for a major national initiative in shipbuilding, with the goal of assisting the efforts of the nation's shipyards to make a successful transition from military to commercial shipbuilding—a competitive industry in a truly competitive marketplace.

Accordingly, the U.S. Department of Defense Advanced Research Projects Agency and the Office of Naval Research requested that the National Research Council, through the Marine Board, study the role of technology in renewing the U.S. shipbuilding industry and the health of the research, education, and training infrastructure that supports shipbuilding. The U.S. Maritime Administration also supported this study.

To address this charge, a Marine Board committee was formed representing broad expertise in ship design, shipbuilding, ship operations, systems engineering, manufacturing technology, education in naval architecture and marine engineering, technology policy, research and technology management, and economics. National Research Council procedures to ensure balance on the committee were followed. Appendix A presents short biographies of committee members.

The study used several methods to obtain a wide range of additional expert views. Three working papers were commissioned, two on technology application in U.S. and foreign shipbuilding (one primarily a literature search) and a third on naval architecture and marine engineering education. Over the course of the study, two workshops were also held, one on technology application in shipbuilding and one on naval architecture and marine engineering education.[1] The National Research Council Board on Engineering Education contributed to the study, notably by participating in the education workshop. In addition, the committee was briefed by numerous representatives of government agencies, shipowners, shipbuilders, educators, and managers of technology. Finally, committee members consulted with the heads of several major U.S. shipbuilding companies in addition to providing their own extensive experience with U.S. and foreign yards. Appendix B details the additional sources of information, including a full list of briefings to the committee.

The committee and the Marine Board hope this report will be useful to a number of audiences. Beyond the study's sponsors, Advanced Research Projects Agency and Office of Naval Research, these audiences are policy makers and technical experts associated with interested public and private agencies, including the U.S. Coast Guard and Maritime Administration; shipyards and shipowners; educators; and others in the marine and shipbuilding communities. The report is a potential road map for shipyard revitalization to maintain a shipbuilding base for defense purposes in a time of declining naval construction.

[1] The two working papers on technology application are by Bunch and Associates and Colton and Co.; the paper on national architecture and marine engineering education is by Raymond A. Yagle. All three of these reports, as well as proceedings of the committee's workshop on technology application in shipbuilding, are available in limited quantities from the Marine Board, National Research Council, 2101 Constitution Avenue N.W., Washington, D.C. 20418.

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BACKGROUND

After decades of outstanding contributions to the nation's naval capability, the U.S. shipbuilding industry is in crisis. During the 1980s, at the behest of the Reagan administration, U.S. shipbuilders turned to constructing many new naval vessels. Following these achievements and with the ensuing defense builddown, U.S. shipbuilders lost significant parts of their business and work force, having become increasingly isolated from world commercial shipbuilding markets. In the mid-1970s, a combined total of about 20 large, oceangoing commercial ships were built every year in all private U.S. yards; since 1984, that number has been 10 or fewer ships every year, with no vessels on order between 1989 and 1991. In the meantime, other shipbuilding nations, aided by generous government support, learned to build ships in series and to capitalize on economies of scale and learning efficiencies.

All of these trends have prompted concern on the part of the U.S. government and others about the potential of the nation's shipbuilding industry to contribute to both military and commercial objectives. The National Defense Authorization Act of 1993 and a following Clinton administration plan, *Strengthening America's Shipyards* (1993), established the goal of a national commercial shipbuilding industry that provides a technology base and research and development infrastructure for achieving both sets of objectives.

In keeping with these developments, the U.S. Department of Defense Advanced Research Projects Agency and the Office of Naval Research asked the National Research Council, through the NRC's Marine Board, to assess:

- the current state of research and technology application in the U.S. shipbuilding industry;
- current and proposed programs that invest in ship design and production-related research; and
- the current state of U.S. education in naval architecture and marine engineering.

This report presents the results of the Marine Board study.

The study was conducted by a specially appointed committee of experts with extensive expertise in a broad array of relevant disciplines. This committee, the National Research Council Committee on National Needs in Maritime Technology, based its conclusions and recommendations on committee members' first-hand knowledge of international shipyards, ship acquisition, and technical exchange agreements between U.S. and international yards and on information obtained through workshops, briefings, and a literature review.

RESULTS OF THE STUDY

Improved technology is critical if the United States is to regain a place in world commercial shipbuilding markets. For the industry to be profitable, it is necessary—although not sufficient— for U.S. shipbuilders to be at least on a par technically with competing international yards. However, U.S. shipbuilders now lag behind in the four major technology categories the committee examined:

- business-process technologies—the principal "up-front" management processes and other management activities, notably technologies for preliminary design, bidding, estimating, and sourcing, that are linked to the marketing capabilities of shipbuilders;
- system technologies—the engineering systems, such as process engineering and computer-aided design and manufacturing, that support shipyard operations;
- shipyard production processes technology—the methods used in fabricating, assembling, erecting, and outfitting vessels; and
- new materials and product technologies—the innovations, including new designs and new components, that meet particular market needs.

Relative to these four categories of technology as they are commercially applied, U.S. builders are somewhat behind in shipyard production technologies, are further behind in system technologies, and are quite far behind in business-process and new product and new materials technologies.

Government involvement in solving what appear to be primarily strategic and operating management problems must be limited. Government agencies should not be involved in the resolution of day-to-day management problems.

Nonetheless, U.S. government agencies can assist U.S. shipbuilders in reestablishing themselves technically in international markets in several ways.

Government can provide better support for "front-end" technologies in product design, product modeling, process modeling, simulation, and costing, all of which are useful to shipbuilders in marketing. These technologies represent the areas of greatest lag between U.S. shipbuilders and their international competitors. Providing help in these areas is the thrust of the Maritime Systems Technology program in Advanced Research Projects Agency. With increased emphasis on the areas of greatest need—for example, by requiring viable business plans for all Maritime Systems Technology projects—the Maritime Systems Technology program should run its course.

Continued support for shipyard production and design technology improvements is also needed for parity with foreign shipbuilders. Although such improvements will likely have only a modest effect in gaining market share, they are still needed for U.S. production costs to be competitive.

The Maritime Administration should continue to serve and should even expand its role as an informed commentator on the industry's effort to become an international player. The Maritime Administration can collect and combine the information gathered by other U.S. government agencies to provide the industry with a better perspective on its competitive position. More useful still, the Maritime Administration could provide a technical assessment of international yards to give the U.S. shipbuilding industry a better picture of the gaps it must overcome. Most important, the Maritime Administration could monitor as accurately as possible the many ways—both direct and indirect—foreign governments subsidize their shipbuilding industries.

Perhaps the most important assistance the U.S. government as a whole could provide would be the procurement of noncombatant ships to commercial specifications using commercial acquisition methods. Although this approach may not be practical for all noncombat ships, their procurement represents the largest single U.S. shipbuilding budget and has the greatest potential for improving overall U.S. shipbuilding performance.

The naval architecture and marine engineering educational system plays an essential but longer-term role in supporting U.S. reentry into the international market by contributing to basic understanding of design, materials, and new production processes. The Office of Naval Research has been a major supporter of the educational structure at the graduate level for many years. This support continues to be necessary for the funding of faculty, Navy projects, and fellowships; however, the educational establishment must become more concerned about the economics of the shipbuilding industry. Little study has been done on the economics of various technologies, even as U.S. shipbuilders are now seriously pressed to reduce labor hours, shorten delivery times, and improve precision to compete in worldwide commercial shipbuilding. For its part, the shipbuilding industry should support the naval architecture and marine engineering educational infrastructure by becoming involved with research that can support the industries.

Shipbuilders should also develop detailed plans to reenter targeted world markets. This is a lesson that management in many other threatened U.S. industries learned quite late. Moreover, all of the ships recently constructed by U.S. yards were for U.S. owners and were competitively priced only among U.S. shipbuilders. The committee must make the sober observation that no industry in a position similar to that of U.S. shipbuilding has become internationally competitive in fewer than 10 years—if at all. Given U.S. industry's current position and the fact that labor hours are twice the international level in some market segments, the industry confronts an enormous task. No other substantial industry with such a low market share has achieved a turnaround in similar circumstances.

This committee urges a broader examination—focused on more than technology—to determine what is required for the industry's success. The charge to the committee limited the scope of the present study to technology; therefore, the committee did not address some issues that could be more important than technology for becoming competitive in shipbuilding. In particular, the proposed examination should cover financing of all kinds, with a close look at U.S. government regulations and subventions by other governments through training programs, port and area development subsidies, and the like, which are not directly tied to shipbuilding but clearly influence its economics. In the past, financing has been far more important than technology in determining the competitive position of shipbuilders, and this will very likely be the rule in the future. The broader examination proposed by the committee could be led by the industry in cooperation with the federal government. The examination should cover the need to meet established goals and to formulate a U.S. public policy approach that creates organizational, structural, and financial incentives. This range of incentives may be essential for building a viable U.S. shipbuilding industry.

POLICY RECOMMENDATIONS

For the present, a number of the measures discussed above could provide valuable support in reestablishing U.S. commercial shipbuilding:

- The Department of Defense should acquire all noncombatant ships, including the ships for the Sealift Program, using totally commercial specifications and commercial procurement practices.

- The Advanced Research Projects Agency should continue its current effort in Maritime Systems Technology, concentrating on the "front end" of the process, including business-process and simulation technologies, in addition to those related to product design.

- The Maritime Administration should expand its role in assisting U.S. shipyards to enter the international commercial market by organizing and presenting information collected from other government agencies; by providing technical assessments of technology gaps U.S. industry must overcome; and, especially, by determining as accurately as possible the direct and indirect subventions and subsidies of foreign governments to their shipbuilding industries.
- The Office of Naval Research should continue to support faculty members through fellowships; through research projects directed at Navy objectives; and, to the extent possible, through projects that have economic impacts.
- Naval architecture and marine engineering schools should become more involved with the U.S. shipbuilding industry through research in business-process, system, and ship-production technologies, as well as by soliciting support for these and other kinds of research. The schools should continue concentrating on subjects traditionally taught but should also pay much greater attention to the economic health of the industry. Universities, with their multiple disciplines, led by the naval architects and marine engineers who justifiably lay claim to being good systems thinkers, should be able to seize the problem that U.S. shipbuilders face; understand what it will take to create a healthy industry; and reach as far afield as needed to understand the cultures, political motivations, and economic infrastructures of international competitors.
- Shipbuilders and shipowners should better support the naval architecture and marine engineering educational infrastructure.
- Shipbuilders and ship owners should develop detailed plans for entry into international commercial markets.

1

Introduction

BACKGROUND

After decades of outstanding contributions to the nation's naval capability, the U.S. shipbuilding industry is in crisis. During the 1980s, under the Reagan administration, U.S. shipbuilders carried out an extensive construction program to renew the U.S. naval fleet. However, as this program flourished, U.S. yards were becoming increasingly isolated from major developments in the world's commercial industry. During that time, other shipbuilding nations, particularly South Korea, Germany, and Japan, concentrated—often with the help of new forms of government assistance—on building ships in series, benefiting from economies of scale and learning efficiencies. Between 1974 and 1993, U.S. shipbuilding for the commercial market declined precipitously. In the mid-1970s, a combined total of about 20 large oceangoing commercial ships were built every year in all private U.S. yards; since 1984, that number has been 10 or fewer ships every year, and no vessels were on order at all between 1989 and 1991 (SCA, 1993). Since 1985, Japan and Europe have supplied the dwindling number of commercial ships built for U.S. owners. Finally, after 1990, with the end of the Cold War, U.S. shipbuilders lost significant military work, as well as a large part of their work force. From any perspective, then, the U.S. shipbuilding industry confronts enormous challenges.

At the same time, there are new potential roles for the U.S. shipbuilding industry. The Maritime Administration (MARAD) has estimated that between 5,500 and 7,500 large oceangoing ships will be built for the commercial market between 1996 and 2001, largely to replace an aging world fleet (Executive Office of the President, 1993). These figures compare well with figures from a recent study for the National Shipbuilding Research Program (NSRP). That study predicts a market of about 1,130 ships per year (NSRP, 1995). During the late 1980s and early 1990s, the international market experienced a combination of rapidly increasing world shipbuilding costs relative to the United States, along with increased demand, especially for tank vessels, and an associated rise in ship prices ($60 million to $100 million for very large crude carriers). This situation was forecast by Temple, Barker & Sloane (1990). This shipbuilding market situation became very evident to the Clinton administration policy-setters when they established the five-point shipbuilding initiative described in the following paragraph. Since 1993, the international market has changed again. The spurt of new ship orders in the 1989–1992 time period, plus the Desert Shield/Desert Storm activities, created a near-term oversupply of ships. This decrease in shipping requirements abruptly decreased the demand for new ships and created a significant drop in prices. However, U.S. construction has become more competitive in the international market because of increasing foreign labor and material costs, competitive U.S. labor rates, and improved U.S. productivity and capacity (Dallas et al., 1994; Temple, Barker & Sloane, 1990).

All of these considerations prompted the U.S. government to consider how it might best support the reestablishment of a commercial shipbuilding industry, with the hope that the industry can serve both commercial and military markets to their mutual benefit. Through the National Defense Authorization Act of 1993, the U.S. Congress specifically required the president to develop "a comprehensive plan to enable and ensure that domestic shipyards can compete effectively in the international shipbuilding market." In October 1993, the Clinton administration issued a corresponding five-part plan, *Strengthening America's Shipyards* (Clinton, W.J., 1993).

The nation's goal, according to this plan, should be to assist the efforts of the nation's shipyards to make a successful transition from military to commercial shipbuilding—a competitive industry in a truly competitive marketplace. The plan points out that such a proposed transition program is consistent with federal assistance to other industries seeking to convert from defense to civilian markets.

Three parts of the administration's plan concern financial issues: ensuring fair international competition; financing ship sales through loan guarantees; and assisting in international marketing. Another part of the plan is aimed at eliminating unnecessary government regulations to increase U.S. competitiveness. The fifth part of the plan intends to advance the industry's competitiveness through a government cost-sharing program that features industry-initiated research and development projects in technology transfer and shipbuilding process change.

More specifically, the five elements are as follows:

- Level the playing field for foreign and domestic subsidies, both direct and indirect, through formal agreement of the Organization for Economic Cooperation and Development (OECD).

- Develop manufacturing and information technologies for ship design and production through the Maritime Systems Technology (MARITECH) program of the Department of Defense's Advanced Research Projects Agency (ARPA), in part by encouraging needed alliances among customers, suppliers, and technologists.
- Eliminate unnecessary government regulations in such areas as procurement, standardization of international construction standards by the U.S. Coast Guard, and updated Office of Occupational Safety and Health Administration standards.
- Finance foreign-flag as well as U.S.-flag sales through Title XI loan guarantees.
- Provide executive-branch assistance with international marketing.

SCOPE AND OBJECTIVES OF THIS STUDY

In keeping with these developments, ARPA and the Office of Naval Research (ONR) asked that the National Research Council (NRC), through the Marine Board, conduct a study of the potential role of technology in revitalizing the U.S. shipbuilding industry and of the health of the shipbuilding industry's infrastructure for research, education, and training.

The Marine Board's Committee on National Needs in Maritime Technology was formed and was given the following three-part charge:

- Assess the current state of research and technology application in the U.S. shipbuilding industry and identify changes that could assist in making the transition from the current state of the industry to an internationally competitive state and convene a workshop to assist in this part of the project.
- Assess current and proposed programs that invest in ship design and production-related research and identify appropriate changes that would improve their effectiveness and contribution to the goal of an internationally competitive U.S. shipbuilding industry.
- Assess the current state of U.S. education in naval architecture and marine engineering and identify steps that should be taken to strengthen the education base to achieve national shipbuilding goals. If appropriate, convene a workshop to assist in this part of the project.

This report addresses these three tasks in the manner described at the end of this chapter under "Organization of the Report." First, however, some additional background is given on the shipbuilding industry's structure and employment, on potential commercial markets for large U.S. shipbuilders, on past and present forms of support for the U.S. shipbuilding industry, on foreign government support of their shipbuilding industries, and on the recently signed OECD agreement to terminate a wide variety of subsidies to the shipbuilding industries of signatory nations to promote more equitable and productive competition.

Although there may be a military benefit to having a viable commercial shipbuilding industry, neither the administration's plan nor the charge to the committee addresses the national capability for naval shipbuilding. The subject of building military ships is discussed only to the extent that practices developed to build ships for the Navy may help or hinder commercial ship production.

INDUSTRY STRUCTURE AND EMPLOYMENT

The following discussion briefly describes some critical characteristics of the U.S. shipbuilding industry with regard to the industry's competitiveness.

Size

The employment level of shipyards is sometimes difficult to determine because many shipyards are both shipbuilding yards and ship-repair yards. The U.S. Maritime Administration reports employment levels for both types as shipyard employment; therefore, none of the 21 shipyards they consider capable of building large oceangoing ships has built any ships recently. In addition, there are several smaller shipyards, many under common ownership, that are developing the concept of the "virtual shipyard" and are operating together to form what can be considered yards of more than 1,000 employees. Total employment at the 21 major private U.S. shipyards in 1994 was about 75,000. Total employment in private U.S. shipyards was about 107,000 during 1994 (MARAD, 1994). That figure for employment represents a steady decline since 1982, when about 172,000 people were employed in all private U.S. shipyards. These figures are for shipyard employment only and do not include suppliers and related employment, which would more than double the number. The Shipbuilders Council of America estimates that, if present industry trends continue, a total of 180,000 shipyard, supplier, and second-tier and support jobs could be lost by 1999 (SCA, 1993).

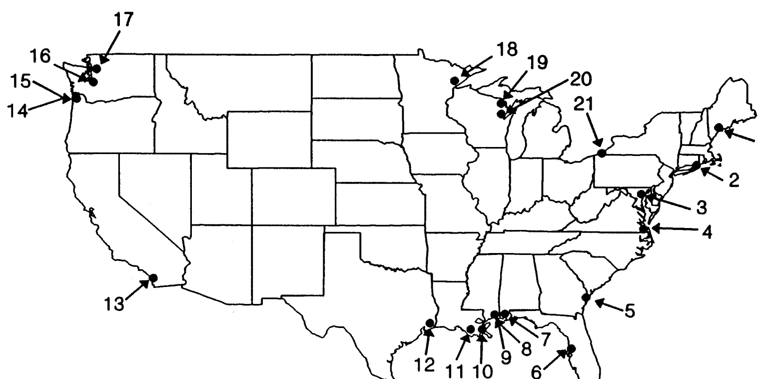
Although the term "shipyard" generally includes both shipbuilding companies and ship-repair companies, this study is restricted to shipbuilding companies, and further, to those shipbuilding companies that can build large, oceangoing ships. Ship repair may share some of the same facilities and personnel as shipbuilding; however, the production process is very different. Moreover, many builders of small vessels are currently competitive and even leading in the international market for their products. These builders of smaller vessels have been examined by the committee for beneficial practices. Factors for successful competition cited by small shipyards include improved efficiency from less complex management organizations, the ability to change products quickly to enter new markets, and a willingness to price products at a loss in order to enter new markets. In the committee's analysis here, there are three size categories of active

TABLE 1-1 U.S. Builders of Large Oceangoing Ships by Work Force Size

Size of Shipbuilder	Number of Employees	Number of Companies
Large Established	More than 3,000	4
Medium, Emerging	1,000 to 3,000	3
Small	Less than 1,000	12

U.S. large, oceangoing shipbuilders, as expressed by the number of their employees (Table 1-1). Most of the employees of these 21 companies are involved in building U.S. Navy vessels, which will be true through 1997 and perhaps beyond. The names of these shipbuilders and their locations are shown in Figure 1-1.

MARAD has sometimes used a different, but related, classification of shipbuilding companies. MARAD distinguishes "major" shipbuilding facilities, which can construct vessels of at least 400 feet in length, from "second-tier" facilities. According to this classification, there are 21 major facilities in the United States. Second-tier shipbuilding facilities are those remaining, that is, those that construct vessels smaller than 400 feet. Second-tier facilities number about 100, and



1. Bath Iron Works Corp.
2. General Dynamics - Electric Boat Div.
3. BethShip, Sparrows Point Yard
4. Newport News Shipbuilding
5. Intermarine USA
6. Tampa Shipyards, Inc.
7. Alabama Shipyard, Inc.
8. Halter Marine, Inc., Moss Point Div.
9. Ingalls Shipbuilding, Inc.
10. Avondale Industries, Inc.
11. McDermott Shipyard
12. Trinity Marine Group - Beaumont Div.
13. National Steel and Shipbuilding Co.
14. Gunderson, Inc.
15. Portland Ship Yard
16. Tacoma Boatbuilding Co.
17. Todd Pacific Shipyard Corp.
18. Fraser Shipyards, Inc.
19. Marinette Marine Corp.
20. Peterson Builders, Inc.
21. Erie Marine Enterprises, Inc.

1994

FIGURE 1-1 Major shipbuilders in the United States and their locations. (SOURCE: MARAD, 1994).

some of them now compete successfully in specific international markets. Major shipbuilders employ about 70 percent of the U.S. shipbuilding and ship-repair industry's total work force (MARAD, 1994); 90 percent of those workers are engaged in Navy or Coast Guard ship construction and repair work. At the end of 1994, nine of these 21 shipyards were performing only repair and overhaul work, small Navy vessel construction, or non-ship construction work. The MARAD classification is based only on the capabilities of the facilities in the shipyard, not on actual performance. One-fourth of the 21 major shipyards have not built a large ship in the last 15 years.

Ownership

Ownership of the 21 companies shown in Table 1-1 varies. Several are subsidiaries of a larger parent company, several are independent, and several are employee owned. Therefore, the commitment to continued operation during times of financial stress varies, as does the ability to raise capital for investing in improved facilities and processes.

Location

Shipbuilding companies are located on all four U.S. seacoasts. Of the major shipyard facilities reported by MARAD, five are on or near the Atlantic, seven are on the Gulf, five are on the Pacific, and four are on the Great Lakes. The locations are shown in Figure 1-1.

Experience

Most of the 21 companies have neither designed nor built an oceangoing commercial ship in 15 years.

Designs

Numerous types of commercial ship designs can be purchased if a shipbuilder wishes to employ a firm of naval architects. However, several of the builders are developing the capability to generate commercial ship designs tailored to their fabrication methods and facilities.

Building Facilities (Including Waterfront)

Only a few of the 21 companies are capable of building ships of 20,000 tons or more. In many cases, there has been no significant upgrading of facilities since the 1970s. However, several of the builders planning to build ships for the international market have begun to invest in new facilities.

Costs

Builders that have competed successfully in the construction of large, complex U.S. Navy vessels in the past 15 years now find themselves shouldering excess personnel, needlessly complex procedures, and high overhead costs when compared to commercially competitive U.S. and international shipbuilders. U.S. wages are higher than for most Asian shipbuilders, although they are lower than most European shipbuilders. One recent survey showed the hourly rates for workers in U.S. shipyards to be about $18, compared with $10 in Korea and $25 in Japan, Denmark and Germany (Anderson and Sverdrup, 1992). Other factors, including the effect of environmental concerns on such activities as open-air blasting and coating of structure and the additional safety requirements mandated for U.S. workers posed by the Occupational Safety and Health Administration, tend to increase the cost of ship construction in the United States as compared with other nations that do not have such stringent requirements. Few of the companies shown in Table 1-1 can successfully compete with overseas builders of commercial ships at this time.

POTENTIAL MARKETS FOR MAJOR U.S. SHIPBUILDERS

The administration's plan to strengthen the U.S. shipbuilding industry does not identify specific goals to define international competitiveness. Some experts have suggested that capturing 10 percent of the projected world market of 700 to 1,100 ships per year (for the next decade) might be an appropriate measure. The committee believes this view is overly optimistic. A more realistic goal for U.S. shipbuilders to achieve is 3 to 5 percent of the estimated world market. A 30- to 50-ship annual volume would be twice the production level of the 1950s, 1960s, and 1970s. Perhaps a more helpful benchmark might be established with reference to the individual shipbuilder, who might be defined as a full player in the international market when the builder competitively produces the equivalent of four mid-sized (40,000-deadweight ton [DWT]) ships per year.

With regard to U.S. industry's reentry to the international market, the committee also agreed in another fundamental assumption; namely, that to become commercially competitive internationally, U.S. industry as a whole will almost certainly need more (perhaps considerably more) than five years to catch up to international competitors. Recent experience in many major U.S. industries, including automobiles, steel, and construction, indicates that, where industries have been severely challenged by foreign competitors, recapturing a significant market share, under the best of circumstances, requires a considerable period of time.

The shipbuilding market today is clearly better understood as a collection of niche markets. U.S. builders will need to target their products to particular niches to survive. In general, a new shipbuilder in the market, which is the position of every U.S. large oceangoing shipbuilder, should pick emerging market niches unless the market is of sufficiently high volume that securing a modest share can be economical. For example, to compete in the dry bulk ships market with Korea, a nation that is now well experienced in this high-volume market and far ahead in productivity, some other initial advantage may be needed. Although the economies of scale associated with building ships in series help international competitiveness, in some markets small lots can be economically produced. This has been shown by builders in other countries with costs of living similar to those of the United States, as well as by builders in the United States when U.S. yards were stronger participants in commercial markets some years ago.

Table 1-2 shows the classification of world shipbuilding market segments that emerged from a recent gaming exercise sponsored by ARPA and the U.S. Navy in which more than 50 shipbuilding experts, both U.S. and foreign, participated (Dallas et al., 1994). Similar information is provided by a recent study sponsored by the NSRP (Storch et al., 1994). More than half of the forecast market of 1,127 ships per year cited in that study are in the category of "high volume" market. Within that market sector, about 40 percent are bulk carriers, 40 percent are tankers, and the remaining 20 percent are general cargo ships.

Table 1-3 presents the committee's view of the difficulty U.S. shipbuilders face in entering the international market at a profit in selected important segments. The factors that can influence entry include the cost of shipbuilding facilities, market maturity (being well established in a mature market is an advantage), the capability of designing for the market, and the degree of sophistication required. The terms "easy," "average," and "hard" are relative. U.S. shipbuilders trying to market in the "average" category are finding it very difficult.

Similar predictions are made in NSRP (1995) where the market categories "strongly recommended" are for 5,000- to 50,000-DWT tankers, 5,000- to

TABLE 1-2 Global Market Segments for Commercial Ships

Percent of Market	Ship Type	Characteristics
40–45	Bulk carriers	Unsophisticated to design and build. "Easy" technology. Competition among all shipbuilders.
30–35	Tankers	Not too sophisticated to design and build. Again, worldwide competition. Huge Japanese and Korean lead in building this ship type.
10	Container ships	Higher technological skill required. More segmented competition.
10	Specialty market	United States has greatest chance in this part of the market. Unfortunately, low volume of ships.

SOURCE: Dallas et al., 1994.

TABLE 1-3 Difficulty of U.S. Entry to Selected Segments of the International Shipbuilding Market (Committee Estimate)

15-Year Market Size	Difficulty of U.S. Entry to Market[a]		
	Easy	Average	Hard
Large >500 Ships		40K–DWT product tanker	VLCC 40K–DWT bulk carrier
Medium 100–499 Ships		General cargo[b] Complex bulk carriers Container Cruise ships	Simple bulk carriers
Small <100 Ships	High-speed cargo Small chemical and product carriers Reefer ships	RO/RO LNG Cruise ferries	

[a]DWT, deadweight ton; VLCC, very large crude carrier; RO/RO, roll-on/roll-off unitized cargo ship; LNG, liquid natural gas carrier.
[b]Palletized, partial container, break bulk, liberty ship replacement vessels.

20,000-DWT general cargo ships, liquid natural gas (LNG) ships, and passenger ships. That report considers as “recommended with reservations” tankers of 50,000 DWT and above, bulk carriers, refrigerated cargo ships, and roll-on/roll-off (RO/RO) unitized cargo ships.

In short, along with many other experts, the committee believes that it will likely be a niche world in international shipbuilding, and particularly so for the United States in the near term. Although Japan and Korea will probably continue to dominate the tanker and bulk cargo markets, for example, the U.S. could do well in selected markets, such as ships with high outfit content. However, the U.S. domestic market, which is protected by the cabotage features of the Jones Act, is different, and in fact can provide leverage for entering niches in the international market, such as 40,000-DWT tankers.[1]

It is perhaps a contradiction that the 40,000-DWT tanker market is perceived by the committee to be a hard market to enter, yet that market is the first international market for which orders have been placed with U.S. shipbuilders. This success can be attributed to the financing provided by Title XI, as well as the

[1]The Jones Act (Section 27 of the Merchant Marine Act of 1920, 46 App. U.S.C. Sec. 883) restricts noncontiguous, coastwise and inland maritime traffic within and between states and territories of the United States to U.S.-built ships sailing under the U.S. flag.

determination with which shipbuilders are pursuing this market because of the large size of both the foreign and domestic (Jones Act) market for 40,000-DWT product carriers. Likewise, the LNG market, a small niche market, in spite of the higher risk involved because of the cost of licensing and developing required facilities, shows promise for U.S. shipbuilders because of the availability of Title XI financing for these very expensive ships and the sophisticated shipbuilding skills required to build them successfully.

SUPPORT OF THE SHIPBUILDING INDUSTRY

Government can try to support the shipbuilding industry in international competition by:

- reducing government regulations in processes, products, and business practices, when verified to be appropriate;
- providing nationwide tax incentives for modernization (e.g., capital gains tax reduction and investment tax credit), including new facilities that are more productive and quality improvement activities;
- developing training programs to increase skills in yards (in designing, building, or marketing);
- initiating research and development programs to improve materials, processes, and products;
- providing tax incentives for a company to increase exports;
- promoting technology transfer both from within the industry and from other industries and foreign shipbuilders;
- developing training programs in international purchasing, international sales methods, and international financing; and
- encouraging builders in joint ventures with foreign shipyards through the departments of Commerce, State, and Treasury.

LIMITATIONS OF TECHNOLOGY

A precondition of this study was the assumption that technology could make an impact on the U.S. shipbuilding industry and its successful transition into an international industry. It is important to realize that although technology is clearly a major competitive factor in certain industries—particularly industries with lower capital cost products—it is not necessarily a competitive factor in more capital-intensive industries. An analogy is that if you're running a trucking company and have a fleet of trucks, you don't discard your fleet when a new model arrives with new performance technology (unless that technology would make a major dent in operating costs) or with lower acquisition cost. You wait until your trucks wear out and then replace them with the new model. In other words, the process by which the product was made has a relatively small impact on your buying decision.

It stands to reason, therefore, that in the shipbuilding industry, both product and process technology are necessary and essential ingredients to compete, although they do not necessarily lead to a competitive advantage. Process technology will only be able to modify costs and probably will not do enough to influence buying decisions in the face of financing advantages. As discussed in Chapter 2, the committee did not identify any new product technologies that would provide a competitive advantage for U.S. shipbuilders in the international shipbuilding market beyond the niche advantages already achieved.

TECHNOLOGY VERSUS FINANCE

The United States has long supported commercial shipbuilders through subsidies, loan guarantees, and tax credits, as well as cabotage and cargo-preference laws. In the past decade, however, much of this assistance has been discontinued, with the exception of assistance for financing, and the emphasis has shifted from financial assistance to technology-based assistance. This change has occurred over more than three decades of policy development for a multitude of reasons, through significant shifts in both U.S. military requirements and world markets. For policymakers, the paramount issue remains the satisfaction of sealift requirements to maintain a robust national capability for naval force projection and access to the imported goods and raw materials needed to conduct a war and to maintain national economic well-being.

In looking at how assistance programs might help reinvigorate U.S. commercial shipbuilding, the committee remained within its charter of assessing technology investments. Examination of traditional financial incentives, such as subsidies and loan guarantees, falls outside the study's charge. However, nontechnical factors, such as financing, could easily outweigh technology in determining whether the industry survives. The high product cost in the shipbuilding industry, for example, means that financing arrangements can be especially critical determinants of winners in the marketplace. For this reason, as well as to provide historical context, past and present financial programs of support to U.S. industry are briefly reviewed here before technology needs and technology-assistance programs are considered in depth in later chapters.

PROGRAMS OF FINANCIAL ASSISTANCE

Principal government financial programs that support U.S. shipbuilders originated in the Merchant Marine Act of 1936, which has since been amended several times. Programs currently on the books include direct subsidies for ship construction and operation (the construction differential subsidy, or CDS, and the operating differential subsidy, or ODS), loan guarantees (Title XI under the Federal Ship Financing Program), and tax incentives (the Capital Construction Fund, or CCF). When enacted, each was seen as a component of a larger strategy to promote the construction of ships in U.S. yards and crew them with U.S. citizen sailors.

Construction Differential Subsidy

Under the CDS program, U.S. shipbuilders were eligible to receive a subsidy for up to half the cost of building a U.S.-flag vessel. The program was terminated in 1981 as part of a reform program of the Reagan administration. Support for this termination was given by the report of the Grace Commission (1983), which did not support CDS. In addition, the announcement of the U.S. Navy at that time of a goal for a 600-ship fleet provided another argument for terminating the program, as many viewed that construction task as sufficient to occupy virtually all existing U.S.-shipbuilding capacity for more than a decade. Since 1981, no presidential administration has requested funds for the CDS program, and it is effectively dormant. When it was funded, the CDS program created a distortion of the market that was favorable to building of commercial ships for the domestic market by U.S. shipbuilders. Shipbuilders were not able to compensate at the time for the disappearance of that market distortion. Unlike other industries, such as steel and automotive, that also saw the disappearance of market distortions, shipbuilders had a strong military market during the 1980s and, thus, had less incentive to invest in recovering the commercial market.

Operating Differential Subsidy

The ODS program, which seeks to make eligible U.S. ship operators more competitive, primarily by paying the wage differential between U.S.-flag and foreign-flag crews, met a fate similar to that of CDS. Throughout the 1970s, the size of the U.S.-flag fleet declined. In 1981, a determination was made to stop granting new subsidy contracts and to allow existing contracts to expire. Since 1981, no new ODS contracts have been issued.

Title XI Loan Guarantees

Title XI of the Merchant Marine Act of 1936, as amended, established the Federal Ship Financing Guarantee Program. This program offers loan guarantees of up to 87.5 percent on U.S.-flag ships constructed in U.S. yards. Since enactment of the National Shipbuilding and Shipyard Conversion Act of 1993, this program has been authorized to issue guarantees for foreign-flag vessel construction in U.S. yards and for U.S. shipyard modernization projects. Annual appropriations cover the projected cost of projects to the government and administrative expenses. The dollar value of the loans guaranteed is 10 times greater than the required appropriations. Funds appropriated for Title XI annually are on the order of $50 million to $100 million a year, and considerably less than this amount may be spent in the absence of loan defaults. Under the pending OECD agreement discussed below, loan guarantee programs for vessels of OECD participants will be limited to a term of 12 years and a level of financing of 80 percent.

Capital Construction Fund

The Merchant Marine Act of 1970 modified existing legislation and resulted in the current CCF. The program allows U.S. ship operators to shelter pretax revenues in tax-deferred accounts for future use in building U.S.-flag vessels in U.S. shipyards. (The fund can be used for projects other than new buildings, such as for ship modifications and containers.) The benefits of the CCF were reduced by the Tax Reform Act of 1986. However, this program is still in full operation and represents an incentive for U.S. owners to build commercial vessels in the United States for U.S.-flag operation. No U.S. owners have used the CCF in recent years for the purchase of new ships for international commerce.

Discussion

Today, the only clear, internationally competitive U.S. government financial assistance program for U.S. shipbuilders is provided by the Title XI loan guarantee program. Because CDS has not been funded since 1981, ODS operators have no way to build ships in U.S. shipyards, which means that no new ships are eligible for ODS. Therefore, the programs are declining. CDS and ODS, which had been lures for U.S. ship operators to construct vessels in U.S. yards, can no longer have the desired effects due to political decisions made in the early 1980s to phase out such subsidies. The financial advantages of the CCF program have lost their relevance to the construction of new vessels, except for U.S.-flag vessel operators in the Jones Act trade. Also, there is currently little or no demand for U.S.-flag, U.S.-built ships from vessel operators.

Government programs of financial assistance obviously pose an important dilemma. Consistent with economic theory and numerous observations, past programs of financial assistance to U.S. shipbuilders may have retarded certain critical efficiencies that might otherwise have arisen in response to market forces and helped to maintain the industry's commercial success.[2] However, it is important to recognize that U.S. subsidy programs have been undertaken in an international environment in which most foreign shipbuilders received subsidies from their governments or were owned outright or controlled by their governments. However, as a note of caution, the effect of subsidies is not always obvious or beneficial, especially when production far in excess of market demand is encouraged.

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[2]Specifically, the presence of subsidies (e.g., labor, materials, or capital equipment) tends to encourage greater use of the subsidized input. Where labor rates are subsidized, for example, more labor is used than when wages are set by the market, as can be seen in the ODS program.

Although no direct subsidies for ship construction have been available to U.S. shipbuilders since 1981, shipbuilders in all foreign countries are subsidized, both directly and indirectly, by their governments. Hard numbers are difficult to come by, but it is generally agreed that, due in part to foreign government support, foreign competitors have had a clear pricing advantage over U.S. shipbuilders. Substantiation of this position was provided by Transportation Secretary Federico Peña, who stated that "of key interest are the international negotiations to eliminate the shipbuilding subsidies by the countries of the Organization for Economic Cooperation and Development. . . . American shipyards deserve to compete on a level playing field" (Peña, 1993). Shipbuilding countries did not fully disclose the nature or quantity of their shipbuilding support in discussions relating to the OECD agreement. The Shipbuilding Council of America, however, has estimated that South Korea provided an average $2.4 billion in aid annually to its shipbuilding industry between 1988 and 1993; Germany provided $2.3 billion; Japan, $1.9 billion; Italy, $940 million; Spain, $897 million; and France, $634 million (SCA, 1993). In contrast, the last commercial ship constructed in U.S. yards (delivered in 1992) for Jones Act trade cost perhaps $40 million more than a comparable ship would if it were purchased on the international market. Although some view the Jones Act as creating a virtual subsidy paid for by U.S. shipowners, the act actually creates a distortion in trade. Shipowners operating in the U.S. coastal trade are required to buy from U.S. shipbuilders that have only built for the small domestic market, which results in limited production and high prices. Because they are buying from limited production runs, there is a tendency for these owners to order special features that increase the price of ships even more.

Current U.S. market demand (Jones Act) is made considerably weaker by owners and operators delaying ship-buying decisions in the hope—supported by discussions of modifying the Jones Act—of being able to purchase less costly vessels from foreign yards. In addition, the possibility that the limitations on exporting Alaskan oil will be removed weakens that market. Owners assume that the exports will replace domestic markets, which would significantly reduce (by about 60 percent) the number of U.S.-flag ships carrying Alaskan oil.

There are many reasons the market price for ships can vary widely from the cost of construction and can frequently be significantly below cost. Many countries consider a commercial shipbuilding industry important to their economic well-being and offer many means of support, both direct and indirect, for their domestic shipbuilding industries. Subsidies are an example of direct support. Indirect support can take many forms and can vary from training programs for workers to permitting the write-off of loans to cover operating losses. Over the last several years, orders for new ships in the international market have increased, but world shipbuilding capacity has increased even faster; therefore, pressures to provide financial support are increasing even though the OECD agreement eliminates many methods of support, especially direct subsidy. The important aspect of the price versus cost discrepancy to consider is that technology may have an effect on cost, but it will have far less effect on price.

Definitive analyses or conclusions in the area of financial support by government for shipbuilding are beyond the scope of this report. However, current widespread subsidies by competitors and the high product cost mean that financial issues are particularly significant in determining success in the industry. (Appendix C gives a brief overview of specific factors involved in determining the financing of ships and, therefore, the builders from whom ships are ordered.)

U.S. VERSUS FOREIGN SUPPORT OF SHIPBUILDING TECHNOLOGY

The magnitude of government aid for the research and development of ship designs and ship manufacturing technology is one of the most clouded categories covered by the OECD arrangement. Germany, for example, does not report specific projects to the OECD. The Japanese define "subsidy" very narrowly to cover only outright grants but do not include government loans at special terms, equity participation by the government's Japan Development Bank, tax deductions, or the use of government facilities. Such indirect support applies not only to ship production but to materials used in production, including steel. In 1992, in a rare report on the Japanese industry (in the Japanese publication *Kaiji Press*), the government shipbuilding research and development (R&D) budget for 1991 was identified as over $1 billion, including direct subsidies to 44 organizations, such as the Japanese Foundation for the Promotion of Marine Science ($30.3 million) and the Ship and Ocean Foundation ($21 million) (SCA, 1993).

Both public and private investments in developing U.S. shipbuilding technology have been substantially less in the United States than in Europe, according to estimates made by participants at a committee workshop on shipbuilding technology (NRC, 1995). MARITECH's current budget is for $220 million over a five-year period that began in 1994, and MARAD's entire current budget for R&D is less than $2 million. The Department of Defense does invest heavily in technology related to shipbuilding—they provide at least $100 million annually. However, as will be shown in Chapter 3, the thrust of current programs is toward developing warships that have greater military capability cost less and not on the technology for producing commercial ships for the international market.

According to high level technical representatives of European yards who attended the workshop, European yards typically invest about 2 percent of their annual revenues in R&D and about 5 percent in productivity improvement and facilities upgrading. A small yard with building docks and revenues of $250 million a year invests about $18 million a year. A larger European yard with four to six large customers and at least $500 million in revenues spends twice as much ($36 million).

U.S. yards have been investing about one-fifth to one-tenth the equivalent dollar amount, according to estimates of the workshop participants. As a result, U.S. yards first need to catch up with foreign competitors. The workshop participants estimated that large U.S. yards would need to spend between $150 million and $200 million initially to make up the technological deficit in commercial-vessel design and construction, considering the status of U.S. yards and general experience in modernizing obsolete European yards. The need for such U.S. investments is discussed further in Chapter 3.

THE 1994 ORGANIZATION OF ECONOMIC COOPERATION AND DEVELOPMENT (OECD) ANTISUBSIDY AGREEMENT

During the course of this study, on December 21, 1994, the long-sought OECD agreement to end shipyard subsidies and other anticompetitive industry practices was signed by OECD and other shipbuilding countries. Not all of the signatories haved passed implementing legislation in their respective legislative bodies, even though the agreement was scheduled to go into effect on January 1, 1996. Signatories are Japan, South Korea, the United States, Norway, Finland, and Sweden; and the European Union countries, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, the Netherlands, Spain, and the United Kingdom.

The OECD agreement defines the types of subsidy practices to be terminated and provides for enforcement measures, including penalties for violations. Some of the direct and indirect subsidies to be eliminated include government cash subsidies to shipyards for contracts, operations, and improving facilities; some research and development funds; forgiving some shipyard debt; and removing discriminatory regulations and practices. The agreement also identifies a mechanism for bringing complaints for ships sold below cost.

With regard to government assistance specifically targeted at shipbuilding R&D, governments will be unrestricted in the "fundamental research" they can support. Otherwise, they can provide public assistance in the form of grants, preferential loans, or preferential tax treatment up to certain levels of eligible costs. For large yards, aid will be limited to 50 percent of eligible costs for "basic industrial research," 35 percent for "applied research," and 25 percent for "development." If the parties to the agreement concur that R&D is related to safety or the environment, aid levels can be up to 25 percentage points higher for any of the three aid-restricted categories. Small yards can also receive 20 percent more aid for each of the three restricted R&D categories.[3]

[3]In the OECD agreement, small yards are defined as those of less than 300 employees, with annual sales of less than 20 million European Currency Units, or about $24.4 million, and owned 25 percent or less by larger companies.

Issues

The most contentious issues for U.S. shipbuilders in the OECD agreement (and their resolution) were as follows:

- U.S. Jones Act conditions remain in effect, but if U.S. shipyards exceed an annual threshold, the yard that breaches the threshold will not be able to bid against the yards of other signatory nations for one year. The Jones Act market is quite small, amounting to only four ships for all U.S. yards between 1988 and 1993.
- ship financing, notably in the form of Title XI loan guarantees in the United States, has been removed from the dispute settlement procedures and enforcement mechanism that will apply to other practices covered by the agreement. Instead, government-supported financing for ships built in domestic yards for both domestic and export customers will be subject to the terms and conditions of the Understanding for Export Credits for Ships, which is currently undergoing revision. It is expected that 80 percent allowable government financing for ships will have a repayment ceiling of 12 years (instead of the current 25 years) and that interest will be at commercial interest reference rates (CIRRs).
- restructuring aid programs of Spain, Portugal, and Belgium and a Korean shipyard-rescue program were exempted from the original January 1, 1996, deadline.

Thus, the only government support for the U.S. shipbuilding industry remaining after ratification of the OECD agreement will be an abbreviated version of the Title XI program and a more restricted version of MARITECH. (The current MARITECH program offers up to 50 percent cost-sharing of technology development by U.S. shipbuilders. This technology-oriented assistance program is described further in Chapter 3.)

Discussion

Earlier it was pointed out that other factors may be more critical for the immediate survival of the U.S. industry than any technological development. Notably, under the best of circumstances, some period of time will be required for the United States to reenter international markets, and considerations of financing and subsidies, especially as they differ between the U.S. and foreign shipbuilding industries, may predominate in shaping the U.S. industry's future, especially in the near term.

It should be noted that when both international market conditions and currency exchange rates are favorable and the U.S. government has taken an aggressive position in support of competitive shipbuilding, U.S. yards have performed well using advanced ship-design and ship-production technology for that period. However, this is not the case in the international market. A prime example is the implementation of the Merchant Marine Act of 1970, which modernized the provisions of the 1936 act to allow negotiated procurements, direct payments to shipyards using two-party contracts (rather than the more cumbersome three-party contracts), support for bulk as well as liner ships, and a shipbuilding R&D program worth more than $12 million per year at today's dollar value. Eighty modern merchant ships of many types were built under this act during the 1970s. The 1970 act included a provision that successively lowered the allowable subsidy rate each year. Many ships were contracted for at subsidy rates under 38 percent. High-technology, LNG ships were constructed at zero to 15 percent subsidy rates. However, all of the ships constructed by U.S. yards during this period were for U.S. owners only. The ships were competitively priced only among U.S. shipbuilders, not the international market. Although the subsidy system can discourage yards from striving to compete, during several periods the U.S. Merchant Marine acts have encouraged shipbuilding capital expenditures and aggressive marketing by U.S. shipbuilders in the international commercial shipbuilding market. In spite of this encouragement, U.S. shipbuilders were unable to market commercial ships overseas successfully.

This discussion identifies a related nontechnological factor that may weigh more heavily in shaping U.S. industry success than any technology; namely, the U.S. must closely monitor the ratified OECD agreement if the U.S. commercial shipbuilding industry is to survive. Especially in the face of reduced defense budgets, without a level playing field, if other nations continue to subsidize their industries in a greater measure than the United States, U.S. industry faces massive layoffs and yard closures and cannot survive to benefit either from public or private technology development or investment.

ORGANIZATION OF THE REPORT

Chapters 2 through 4 of this report respond to the three elements of the committee's charge. In Chapter 2, on technology application, the committee reviews four major areas to assess the technology needs for revitalizating U.S. commercial shipbuilding. In Chapter 3, significant programs of assistance to U.S. shipbuilding are assessed, particularly in light of the technology needs the committee identified. In Chapter 4, the committee considers current programs in naval architecture and marine engineering (NA&ME) education and steps that might be taken to strengthen the education base to achieve national shipbuilding goals. Finally, Chapter 5 presents the conclusions and recommendations reached in the preceding chapters.

Appendix A provides information about members of the committee. Appendix B provides the names of individuals who made presentations to the committee and the subject of their presentations. Appendix C provides brief background information on international subsidies in shipbuilding. Appendix D provides information beyond that in Chapter 3 on programs to assist shipbuilding. Finally, Appendix E provides information on schools of naval architecture and marine engineering.

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2

State of Technology Application in U.S. Shipbuilding

INTRODUCTION

This chapter discusses four major areas of shipbuilding technologies (which sometimes overlap): business-process technologies, system technologies, shipyard production-process technologies, and technologies for new materials and products. These categories are useful for considering investments in technology, but in operation they interact and overlap. "Technology" is discussed in its full sense, that is, as a practical application of knowledge (or capability thus provided) or a manner of accomplishing a task, especially using technical processes, methods, or knowledge. The concept of technology is interpreted in the larger sense because, as the discussion in this chapter indicates, the biggest challenges to a genuinely competitive U.S. industry are often matters of "soft technology," such as better marketing and cost-estimating techniques, as well as "hard technology," such as new hull designs. Most of the information in this chapter was obtained by the committee through the technology workshop and individual presentations made to the committee, as well as from the committee members' personal experience.

BUSINESS-PROCESS TECHNOLOGIES

Marketing

Beginning in the 1980s with the elimination of construction differential subsidies, U.S. shipbuilders focused increasingly on high-technology Navy ships. Fewer than 20 commercial ships have been ordered from U.S. yards since 1982, and all of these have been for the Jones Act trade. The recent announcement by MARAD and Newport News Shipbuilding about contracts financed under MARAD Title XI loan guarantees to build several tankers for a foreign owner is the first contract to build a foreign-flag ship in a U.S. shipyard since the 1950s. There have been several other promising announcements for foreign-flag commercial ships, but no other contracts from U.S. owners have been announced to date.

Because they are only now beginning to market commercial products overseas, U.S. shipbuilders are seriously deficient in commercial marketing expertise relative to their competitors, who have been successfully doing so for many years. In a recent major gaming exercise, representatives of U.S. shipbuilders, not surprisingly, showed very poor marketing skills compared to representatives of foreign shipbuilders (CNA, 1994).

Marketing in the shipbuilding industry, as in many other industries, is considered here to consist of the following stages: (1) segment definition and analysis, (2) product planning (for segments), (3) pricing, bidding, and estimating, (4) the sales function, (5) individual customer analysis, and (6) after-sales support. Government relations and environmental considerations are also significant marketing factors in the shipbuilding industry.

The consensus of the committee is that the U.S. shipbuilding industry is quite weak in a number of specific marketing areas. These areas include the fundamental understanding of the commercial market and its segments, the mix of buying factors most critical to each segment, and customer preferences and business economics (e.g., such buying factors as the relative importance of price versus financing and product quality versus time to delivery). The industry is similarly weak in responding quickly to the customer during preliminary design, knowing what parts are available, having a well developed ability to offer standardized options, and achieving adequate control over the time required to build.

There are several extensive, reliable, regularly updated databases on shipbuilding and ship operation available by means of real-time, online, user-friendly systems. For about $50,000 annually, shipbuilders can subscribe to three or four systems that are marketed internationally. Raw data, such as individual ship charter terms, vessel prices, cargo flows, schedules, tariffs, and so forth are collected by these firms and “repackaged” in fee-for-service databases. For instance, cargo-flow information is usually purchased from various governments, the OECD, and other international organizations and repackaged for resale; price and vessel-movement information are developed from insurance and charter brokers. A quarterly compendium of historical data, including a set of forecasts for cargo movements and ship construction, is available. Independent consulting firms worldwide also offer tailored assessments for maritime firms, including analyses focusing on particular market segments or geographic regions.

Given these deficiencies in U.S. shipbuilding industry practice, what role could the U.S. government play to support the industry’s development of commercial marketing? Marketing data are hard for government to gather because, when useful, these data favor one company over another. Government must try to avoid favoritism in any actions in support of an industry.

The role of government in developing commercial maritime marketing technologies has been limited to basic data collection such as that associated with customs, census, and vessel registration activities. There is no generally available government source at this time that provides price, vessel-movement, insurance, and other commercially important information. In fact, governments, including the U.S. government, rely on commercial sources for understanding maritime issues and would be hard pressed to match the quality and quantity of marketing information and data already available on the commercial market. While data and information marketing technologies are, therefore, important for the rejuvenation of U.S. shipbuilding, there is little that government can do in this area that is not already being taken care of by the private sector. Moreover, shipbuilders must have people in their marketing departments who are skilled at asking the right questions of the commercial databases and at analyzing the data to suit particular market inquiries and yard projects.

The integrated marketing approach used effectively by foreign shipbuilders is one in which a builder's business processes and technology use are closely coordinated to achieve an overall competitive advantage. Experts in commercial practice suggested that U.S. shipbuilders should follow similar steps, which are already well known to U.S. shipbuilders, although they are far behind in implementing them.

First, evaluate the needs and requirements of the ocean shipping industry for new or converted ships, matching the builder's facilities, capabilities, and financial resources with those segments of the market that make the most sense, that is, those segments that promise the greatest opportunities for growth and for the yard to compete effectively. Shipbuilders should collect and interpret intelligence on trade routes and commodities from commercial and government services; from the builders' marketing and salespeople; and, especially, from shipowners in the targeted trades. The right approach requires more than talking to owners during periodic sales calls; it also requires conducting market research before owners are in the marketplace seeking proposals to meet their needs.

Second, identify specific needs and customers based on the results of the initial evaluation and develop initial conceptual designs. Design studies reflecting research and knowledge of the shipowner's particular trade provide support to sales personnel, especially when a shipbuilder is attempting to penetrate new markets. These studies give the shipbuilder's representatives an entree to the shipowner. In ensuing discussions, the shipbuilder learns more about the needs and insights of participants in the market segments of interest. Resulting ideas are then developed further by the shipbuilder's engineering personnel, who work closely in support of the overall marketing effort. Based on interactions with owners, shipbuilders are also able to refine their targeted markets and conceptual designs.

From the earliest stages, conceptual, preliminary, or contract designs should incorporate production and procurement considerations based on shipyard standards. Later proposals will reflect the quantifiable cost and delivery benefits gained from using these standards.

Steps 1 and 2 form an iterative process, with the feedback from each stage creating new tasks for the other. Data and information collection, formulation of strategies and plans, and interaction with customers and suppliers take place simultaneously and interdependently. U.S. builders of large, oceangoing ships are at a disadvantage because of the separation of naval architecture from shipyard operations and the resulting knowledge barrier. The same barrier between design and production became evident in many U.S. manufacturing industries in the early 1980s.

Third, in later stages of the process, develop a detailed plan to market to an identified short list of potential clients, with the understanding, approval, and support of all key management elements in the company.

Fourth, implement this company plan including, as needed, additional R&D, product development (engineering and design), market testing (obtaining more information from targeted clients), or product-design changes to suit and sell the client (close the shipbuilding contract deal).

Some further observations can be made about successful commercial marketing in today's international environment. The various stages described above require a capable, if small, precontract design and engineering group. Expertise in conceptual, preliminary, or contract designs is not found currently in a number of American yards. The engineering and technical skills to support marketing must be established in-house for U.S. shipbuilders to succeed competitively. Shipbuilders will probably also need to establish field offices or have some of their marketers travel extensively to gather client information at the source. Equally important, shipbuilders will need to come to know clients and their culture. Appropriate leadership will also be required to make the right decisions about marketing intelligence, product-development investment, financing assistance, segment and client targeting, and so forth, as individual contract values can exceed $0.5 billion.

Because the approach detailed above is aimed at a targeted market, the designs developed are suitable frequently for several owners in that market. Thus, chances are increased for series production of similar vessels, with an inherent potential for reducing costs. Standardized designs can still provide variations in capacity (e.g., by varying length at the parallel mid-body portion of the hull), power options, deckhouse arrangements, tank coatings, and so forth, to satisfy owners' preferences.

By providing for these options during design development, the cost and production advantages of standardization can be retained. In practice, owners have found ships built to a suitable shipyard design incorporating custom features are more economical and preferable to ships constructed to owner-developed customized designs, if the selling price reflects the substantial savings in cost and operating expenses inherent in that approach. (Standardization and its advantages are discussed at greater length below.)

A shipbuilder's skill in this approach can lead to unilateral or participant-restricted negotiations avoiding the less preferable option of participation in worldwide bidding. Most major buyers prefer to deal with shipbuilders they have confidence in based on previous satisfactory relationships.

Marketing can be and has been assisted by the U.S. government, including increased emphasis by the Department of Commerce at U.S. embassies. The Maritime Administration is developing shipbuilding market data and analytical capability for use in policy-making. This data will also be used in consulting with shipbuilders, especially the smaller yards, which cannot afford a full market research capability. Through the use of electronic bulletin boards, common data sets are being developed so that shipbuilders can base their analyses on the same data sets to the greatest degree possible. Industry, in general, cannot rely on government for much market research because the most beneficial information is developed in house, directly through competition and in coordination with other yard functions.

Because of their long absence from the world commercial shipbuilding scene, U.S. shipbuilders have not had the opportunity to develop either long-standing relationships or favorable reputations with prospective international commercial customers. An international ship broker reported to the committee that the image of large U.S. shipbuilders has also been tarnished by reports of difficulties with the U.S. Navy, their principal customer in recent years. An international view is that U.S. shipbuilders are difficult to deal with, rely on lawyers and the threat of litigation to settle disputes, are unreliable in keeping delivery commitments, and attempt to remedy frequent cost overruns by seeking costly contract changes. Both U.S. shipbuilders and others familiar with the circumstances maintain that many of these problems result from the way the U.S. Navy negotiates and administers its contracts—the number of inspectors and auditors from the local U.S. Navy Supervisor of Shipbuilding can number in the hundreds for each ship under construction. Even if true, these explanations may not diminish unfavorable perceptions of the U.S. yards in the eyes of prospective international customers.

Short of a wholesale overhaul of U.S. military procurement, the U.S. government cannot remedy this problem directly. However, government may be able to help shipbuilders gain an initial footing to prove themselves. Government does have a unique position with regard to international customers for U.S. vessels in that it may tie the purchase of U.S.-built ships to other international transactions, including commercial and military aid. Government can also intercede through diplomatic channels or use intelligence assets to assist U.S. shipbuilders. However, there is considerable danger of being accused of industrial espionage or "strong-arm tactics" that interfere with national prerogatives. Use of U.S. government-sponsored foreign military sales also provides an outlet to international markets, but these contracts do not assist in the marketing of commercial ships.

Bidding and Estimating

The real costs of a U.S.-shipyard product are very difficult to evaluate using current information management systems; yet, evaluating real costs is essential for commercial practice, beginning with estimating and bidding. Current systems were designed to meet Navy specifications and regulations. In addition, they were designed to support an outdated approach to ship construction in which ships were designed and constructed system by system. U.S. shipbuilders find it difficult to estimate the costs of new ships for these reasons.

Activity based costing (ABC) is one potentially sound approach to cost estimation in a commercial setting. ABC allocates both direct and indirect costs according to an estimate of the resources actually expended by business units or product divisions in a corporation. The chief advantage of ABC is that it allocates so-called overhead costs according to actual utilization rather than according to direct labor hours or aggregate production costs. In ABC, production activities are allocated overhead and other costs according to actual consumption of corporate resources, such as sales, marketing, administration, and other activities, rather than by averaging across all activities.[1]

Good commercial cost systems identify all the real inputs to a product; the value of system calculations depends significantly on the architecture of process simulation (a technology addressed further below). Because of shipbuilders' current use of the government "bid package approach," wherein a generic product specification is developed that can be manufactured by many suppliers, for example, specific component information is lacking that could make any one supplier's product most suitable. This information is critical for commercial bidding and estimating.

Estimating and bidding should represent the wisdom of the right interdisciplinary shipbuilding team. At one successful foreign shipbuilder, relevant technical, financial, and organizational expertise are directly involved in the bidding

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[1]The following definition and rationale is offered by Michael O'Guin (*The Complete Guide to Activity Based Costing*, Prentice Hall, New Jersey, 1991, p. 31), "ABC assigns costs to products or customers based on the resources they consume. The system identifies the costs of activities such as setting up a machine, receiving raw material, and scheduling a job. ABC then traces these activities to a particular product or customer that triggers the activity. Accordingly, the product's costs embody all the costs of these activities. Overhead costs are traced to a particular product rather than spread arbitrarily across all products. In turn, management can learn to control the occurrence of activities, and therefore, learn to control costs."

process, with the head of the yard and high-level representatives from finance and engineering participating in the cost-estimation process for new ships. More generally, for successful commercial practice, U.S. shipbuilders must have engineers who better understand costs and financial experts who better understand engineering.

Product Differentiation

U.S. shipbuilders also lack good parametric design capability. Automated basic design systems that yield ship weight and cost estimates along with other information are available. Based on specification of such parameters as (for a cruise ship) number of passengers, berthing and dining area per person, and ratio of crew members to passengers, a system design for the ship can be obtained independent of hull type. Weight and cost estimates can be derived from this system design.

Automated design can be used to produce the greatest number of alternative designs, together with their total economy calculations, for the commercial customer's consideration. The following measures have been reported to be critical for automated design systems:

- Develop a small but extremely competent commercial ship design and engineering staff that is not burdened by military projects and the associated paperwork.
- Eliminate procedures in the commercial technical group that are required for compliance with Federal Acquisition Regulations (FAR) and other military contract requirements.
- Select up-to-date ship design and engineering software to run on personal computers that are interfaced to UNIX workstations for greater computer power when needed. Ship design computations should be performed using a common database that is carried forward into production.
- Develop a detailed dual-cost computerized database system that can load historical Ship Work Breakdown System data and is product/unit-oriented to reflect how ships are now built in the yard. These systems should be cross-correlated, and the entire system should be set up to estimate the cost of large blocks for outsourcing.
- Use these detailed databases to develop quick, order-of-magnitude estimates on a parametric basis.
- Establish detailed (micro) cost-evaluation procedures, using industrial engineering/process standards techniques, to assist the ship design group in measuring the improved producibility of their designs. These cost-evaluation procedures should be related to empirical cost data.

Sourcing

Effect of Navy Procurement Practices

For more than a generation of professional shipbuilders, the U.S. shipbuilding industry has been obliged by its primary customer, the U.S. government, to develop, design, market, and build ships following a comprehensive set of detailed ship acquisition rules and procedures. In recent years, these rules have been somewhat consolidated. Most of them have been documented and codified under FARs.

A prime purpose of these regulations is to control a huge procurement system (the U.S. government) and prevent buying decisions based on personal judgment, technical bias, or personal gain. Because military ships (including U.S. Coast Guard, Army, and Navy ships) are generally large and immensely complex, applying FARs, together with the vast array of other federal regulations, creates inherently inefficient design, engineering, and procurement procedures for both government and industry suppliers (the shipyards). Business methods developed to meet government procurement requirements are now entrenched in U.S. yards, especially those of private-sector warship builders and, to a lesser extent, U.S. Navy auxiliary ship constructors. Some of these shipbuilders are changing their methods so that they, like those few U.S. shipbuilders that have operated largely in a commercial shipbuilding market with a minimum of government involvement, will soon be able to operate in the international market.

The problems noted also have affected U.S. ship design firms, which have worked for many years under long-term, level-of-effort contracts from government agencies. European observers have reported a "productivity difference factor" of about three; that is, for a given commercial ship, a U.S. design firm uses about three times as many labor hours as a non-U.S. firm. In addition, producing a commercial design for the Navy requires about three times the labor hours of a design for an equivalent commercial ship because of the Navy's design rules and review processes.

If U.S. shipbuilders are to compete internationally in commercial markets, they will clearly need to maintain closer ongoing relationships with worldwide vendors of major components in advance of procurements. They will also need to practice better just-in-time purchasing of materials and emphasize performance (rather than design) specifications in purchasing.

Procurement Practices

The alternative models of procurement listed below represent progressively closer supplier relationships:

- traditional contracting for components through requests for bids;
- long-term sourcing relationships with networks of suppliers; and

- material control (with yard personnel working directly with suppliers to ensure the use of new technology, quality, and timeliness).

The procurement practices of U.S. shipbuilders are far less advanced than those of foreign competitors for commercial work. U.S. shipbuilders have tended to follow the first of the three models, generally placing detailed design specifications out for bid rather than trying to satisfy needs by less-tailored means, such as relying on vendor catalogs and using performance specifications based on a vendor's known capabilities. (Problems in using design, instead of performance, specifications are discussed below, under the section on standardization. See also the related discussion in Storch et al., 1994.)

One U.S. shipbuilder's representative reports, for example, that one of their most significant problems is the time required to get material because of the delay in getting vendor-furnished design information or (for government work) getting multiple quotes and justifying the choice of vendor. A significant amount of material now used by U.S. yards is, in fact, of foreign origin; but, although foreign acquisitions are common, continuing relationships with suppliers are not. This leads to critical time lost in procurement, especially when seen from the vantage point of commercial operations.

Foreign shipbuilders depend, instead, on small groups of suppliers with whom they have closer, longer-term relationships—relationships that often reflect other features of the "material control" model, such as a yard working with suppliers to ensure the use of new technology. Foreign shipbuilders also emphasize just-in-time approaches to material management, beginning with identification and purchasing, through warehousing, marshaling, handling, and assembling (Storch et al., 1994).

Because U.S. shipbuilders fail to emphasize just-in-time material purchasing and management, significant extra waste, rework, and monitoring result. Capital is tied up unnecessarily in stored goods and storage area. The current method of procurement is encouraged by U.S. Navy procurement practices, which provide progress payments based on completion of milestones. U.S. shipbuilders should develop more of a just-in-time approach to material purchasing and management to reduce inventories and associated storage problems.

U.S. shipbuilders will have to obtain many of their innovative components and materials from foreign sources. For example, various steel shapes used by foreign shipbuilders for improved productivity and reduced structural weight are not available from U.S. suppliers. This is also true for other important materials and components, most notably large castings and slow-speed diesel engines. Where there are U.S. suppliers for shipbuilding components and materials, virtually all produce for the U.S. Navy, according to government regulations and specifications. There are vast differences in manufacturing practices between producing for the Navy and for the commercial world, and generally U.S. firms are not price competitive when supplying commercial components.

Until domestic suppliers offer such commercial items for sale, U.S. shipbuilders must rely on foreign suppliers. However, U.S. builders are at a significant price disadvantage because they have not maintained working relationships with foreign suppliers. Even after U.S. builders turn to foreign vendors they will probably remain at a disadvantage in terms of delivery schedules, owing to their small, initial levels of demand and the newness of their vendor relationships.

There are great sources of supply outside the United States that provide less expensive, high-quality materials that are available for immediate delivery. Offshore designers are often more familiar with the materials and production processes used overseas. Storch et al. (1994) recommend that U.S. shipbuilders develop a database of worldwide suppliers, along with some means of recording supplier performance.

Shipbuilders must work with vendors before projects to begin to understand what material is available worldwide and to develop specifications for components. Like their foreign competitors, U.S. shipbuilders will need more multilingual managers and engineers. (Worldwide source catalogues are not readily available in the United States for major or minor components, such as pumps, motors, and winches.) U.S. shipbuilders must use all appropriate means to build sourcing capability to compete in international markets. For example, purchasing offices should be set up abroad and shared by several U.S. shipbuilders.

Marketing Niche Strategy

Earlier it was noted that U.S. shipbuilders must target niche markets because the yards will find it difficult to compete in high-volume production markets where foreign competitors are well entrenched. U.S. shipbuilders must apply their use of technology in business relationships as well. They must select shipbuilding market niches in which they can be competitive, adapt the technologies required to develop competitive products, apply the product technologies required to differentiate their products (ship designs) from competitors' products, develop the process technologies required to design and build these products competitively, and last but not least, develop strategies for the procurement of everything the yard cannot make efficiently.

The last point is key to becoming competitive. If the right market niches are chosen and competitive products are developed, then maximizing total throughput for a given facility and labor force is critical to making money. High throughput in manufacturing is achieved by engineering products for efficient subcontracting of significant portions. In other words, maximize outsourcing to maximize total production throughput and revenues from a hard-core shipyard asset base and labor force. This approach keeps the work force at a smaller, more stable, more manageable size, with resulting higher employee motivation and productivity. This approach is far different from that of today's larger, government-oriented shipbuilders. In that approach, progress payments encourage large in-process inventories, and little need is seen for greater subcontracting or related new technology beyond that which is developed under government-sponsored research. U.S. shipbuilders frequently need to build up quickly to peak capacity for specific contracts, but they tend to do this by rehiring laid-off workers.

In addition to developing technology to better outsource, such as better large-unit assembly/block planning and better accuracy control and quality assurance procedures applicable to subcontractors, U.S. shipbuilders need to develop appropriate business relationships with suppliers. These relationships should not be based on the traditional lowest-acceptable-bid response; suppliers should be considered as partners in shipbuilding. This requires developing the business, technical, and marketing skills and facilities for outsourcing work to subcontractors, and having representatives, including members of the engineering staff, available to the outsourcing contractors developing the design and specifications of products. Setting up and nurturing a network of supporting outsource contractors or teaming relationships with competing shipbuilders to construct large parts of a ship is something U.S. shipbuilders are beginning to consider. Several of the current MARITECH projects feature partnering in the development of new ship designs and methods for producing ships.

Even more basic than implementing a good outsourcing plan is establishing good business relations with international marine systems and equipment suppliers. U.S. shipbuilders must implement new technology developments, especially those developed abroad, and incorporate them into their designs, using the engineering expertise of the system supplier wherever possible. The builders should work the technology of the supplier base, rather than issuing shipyard-developed system specifications, and then try to obtain the best supplier base prices.

Human Resources

As indicated in the discussion of marketing above, the engineering manpower and skills needed for successful integrated marketing and design are not currently found in a number of U.S. yards. In the recent past, designs have usually been developed by government agencies (most often the Navy) or naval-architecture design agents who are not associated with shipbuilders. However, in-house skills to support the marketing functions described must be developed or strengthened. Engineering staffing must satisfy the needs for design personnel availability in support of marketing.

The question often raised is whether the high quality of Navy standards and workmanship may be an impediment to U.S. shipbuilders' commercial work. However, committee experience would suggest that this is not an issue. Even though the presence of Navy inspectors is more pervasive in a shipyard than is the presence of inspectors from classification societies, the latter enforce their standards as well as, if not better than, Navy inspectors. In fact, the U.S. Navy uses inspectors from the American Bureau of Shipping to supervise structural fabrication of noncombat, and even some combat ships. Shipbuilders representatives report that some commercial standards are higher than Navy standards (such as those relating to pre-Stealth superstructure fairness). Although experience in other industries indicates that the blue-collar work force may require months to adapt from military to commercial projects, in basic shipyard processes such as steel fabrication, this transition can occur in weeks. Extensive planning is required for this transition, but most of it is associated with the new product line. The transition from building commercial tankers to building passenger ships would be no different than the transition from building aircraft carriers to building tankers. The latter observation provides some support for the idea that "dual-use" yards—yards producing both military and commercial ships—can be maintained successfully.

While the adaptability of direct labor is probably not so much a problem, the size of the current work force is, to some degree, a problem. There has already been downsizing already in the industry, and further downsizing would very likely accompany a shift from Navy to commercial work. Most European and Pacific Rim shipbuilders have high levels of efficiency in production, although for most countries, except Korea, labor rates are higher than in the United States. For U.S. shipbuilders to compete, they must also achieve these efficiencies. The result, however, will be fewer employees in the yard. Some currently competitive international commercial shipbuilders have also found it valuable to keep the work force down to a minimum, stable size (with some guarantee of job security), using outsourcing and subcontracting as needed. Subcontracting is used for a specific part of the ship, such as designing, fabricating, and installing the piping system. A major problem for U.S. industry has been the sporadic nature of the workload, which for many shipbuilders has led to problems of productivity and quality, such as the need for greater rework. Subcontracting the work may, therefore, provide some solutions, as it has for certain Japanese and European shipbuilders.

For similar reasons, motivation and training of the work force, by forming worker teams and cross-training, may both be significant issues in the near future. Developing good incentive systems, such as yardwide profit-sharing used in European yards, might also prove useful.

One U.S. shipbuilder has supported a major training initiative in quality-management process to reorient company culture and individuals away from the practices of the past, which were heavily influenced by U.S. Navy requirements, toward the simpler processes used by international competitors. This kind of initiative may be extremely valuable; at the same time, it obviously does not provide the full structure of a commercial management system.

The committee agreed that, in the area of human resources, the managers of U.S. yards, not the direct labor force, need to change most for the yards to compete in the world marketplace. Military administrative systems are far too laborious to support viable commercial enterprises. In addition, managers of commercially successful yards will have to be as proficient in technology as they are in management.

Information Management Systems

As the discussions above suggest, U.S. shipbuilders lack the information management systems to compete in world markets. Marketing systems are not designed to gather and analyze customer data; bidding systems are slow and relatively inflexible; and cost systems are designed to meet military, rather than commercial, needs. While the United States clearly has adequate computer hardware for the industry to compete, hardware/software systems have not been designed for commercial shipbuilding practice. Software packages vary widely in their competitiveness. Management systems must provide up-to-date, pertinent information of the right kind and level of detail through a user-friendly format (including any helpful color graphics). Information systems must be flexible, integrated, and distributed. The systems now used in U.S. yards generally do not meet commercial needs.

The flexibility of systems means that, as shipbuilding activities are changed or reengineered, the various control, tracking, and accounting systems can be adapted quickly to the new circumstances. Optimally, this would mean that prior to a change in a shipbuilding activity the management system would be able to simulate the impact and weigh it against other possible changes.

The management system should be integrated in the sense that it can interact with and use information and data from the yard's various cost, accounting, labor, design, scheduling, and production systems. Integration would mean that progress could be monitored in all aspects of design, construction, and outfitting and that the impact of scheduling changes in one part of the yard on throughput in other parts of the yard could be assessed. Optimally, the system should include all suppliers, linking the elements of the enterprise.

Systems should also be distributed and accessible by different activities in the yard, so that work flow and scheduling can be adjusted by this means as well. Useful data systems will permit wide access and data entry, although completely free access and entry could raise serious problems. Technologies that might achieve such a distributed system include local area network (LAN) and wide area network (WAN) system arrangements. Advances in such technology can be found in both U.S. and foreign shipbuilders. However, even though the general level of application of such computer technology is high in the United States, and therefore available, U.S. shipbuilders have been slow to apply it.

In short, management systems should combine software and hardware in PC-based systems to support rapid communication, monitoring, and controlling. The systems should permit high levels of data integration widely distributed among different disciplines and activities in the yard and should exhibit a high degree of flexibility to be responsive to market changes.

Technologies for developing shipbuilding strategies and plans range from commercial off-the-shelf software for personal computers to large, custom, integrated systems fed by a shipbuilder's materials requirements, process, accounting, design, and architecture activities. Such simulation is related to simulation of shipbuilding processes as discussed in a following section.

The type of information and sophistication of methods need not be extreme for shipbuilders to realize considerable benefits. Properly specified, general objectives and the impact of changes in strategic thinking can be modeled on simple spreadsheets. More precise estimates can be developed and tailored from existing accounting system information or from other statistical data collected in the course of past ship construction. Thus, a shipbuilder may be able to develop a sufficiently accurate understanding of potential in a market with readily available software and internal resources.

There is a significant difference, however, between developing a notion of market potential and actually bidding for the construction of ships. The latter involves the ability to adjust prices based on customer requirements and trade peculiarities, including cargo handling infrastructure, draft, beam, and other dimensional restrictions, and scheduling requirements. To make such adjustments, a shipbuilder must be able to recalculate a vessel's construction cost quickly and accurately as bids are refined in competition. All of this recalculation can be, and in the past was, done by hand; however, today, through the use of cost models tied into shipyard design and materials databases, very precise estimates of cost may be achieved in short order (perhaps several days). The technologies required to accomplish such calculations are available commercially today although each implementation must be customized for each yard.

There are also emerging information technologies that can support rapid and accurate communication of technical data among suppliers, outsource contractors, and shipyards. With a good understanding of outsourcing and supplier base-engineering support, these technologies can be used to facilitate the process of moving the work and the knowledge skill to outside suppliers to increase throughput revenues and profits.

Technologies to assist in the interaction of customers and suppliers are significantly more advanced in the commercial world than in government. Activities such as "electronic commerce," where transactions are automated, and ordering, inventory, accounting, and funds transfers/payments are far better developed by private sector firms than by government organizations.

Insofar as U.S. shipbuilders will need to specialize in niche markets for the foreseeable future, yard management systems must also be designed to support the economic production of small order quantities. The shipbuilders could also develop better information management systems by building, say, six or seven commercial ships per year (perhaps through subsidy support or a requirement for cargo reservation for U.S.-built ships); however, such an approach is not required for the development of commercial information management systems, as experience at some foreign private shipbuilders has shown.

The current Sealift program, through which U.S. shipbuilders construct commercial-type auxiliaries for the U.S. Navy, provides little help in developing commercial management systems because Sealift comes under Navy management control practices. In building Navy ships, for example, shipbuilders have to respond to many more on-site supervisory personnel (often 10 times as many or more) than when handling commercial contracts.

If the current Sealift ships were defined only through performance requirements, without invoking government procurement requirements, and thus were purchased by the Navy in the same way that commercial buyers procure ships, perhaps 90 percent of the benefits of producing a commercial ship for the international market might be obtained. The success of this strategy depends, of course, on the Navy's confidence that shipbuilders are willing and able to develop designs and on the Navy's willingness and ability to absorb the cost (partial or total) of unsuccessful designs. The Navy's ability to absorb these costs would also determine the number of participants in the program. The short-term increases in cost could be offset in the long term by decreased management costs of shipbuilders. This concept would fit well with the increased emphasis by the U.S. Navy on affordability and versatility.

One important subject with regard to the committee's study charge is whether U.S. shipbuilders can effectively function as "dual-use" yards; that is, whether both military and commercial work can be carried out effectively within the same yard. Although committee members had varied opinions on this subject, the consensus finally reached was that dual-use production raises difficulties but is possible and may be a practical necessity for many U.S. shipbuilders in the current market environment. Many U.S. shipbuilders have produced military and commercial ships simultaneously over the past 40 years. Dual-use production has been less common in recent years; however, several U.S. shipbuilders are now working, with foreign-shipyard assistance, to move from full military production to joint military-commercial production.

Some of those experienced in this subject reported that segregation of facilities and work force is not required for dual-use production, although certain work practices developed on Navy projects would not be cost effective for commercial projects. However, military and commercial management and technical support groups must be separated, and two different sets of technology standards and business practices must be maintained. For dual-use production to succeed, management must not let complicated government-contracting practices creep into the commercial work. Some experts also recommended keeping common facilities and other indirect costs in a common overhead pool, especially for very expensive capital assets, such as drydocks and fabrication halls. With this practice, the yard's overall overhead pool costs will be effectively distributed. Competing in both military and commercial markets is a real challenge for yard management, but potential rewards include reduced long-term business risks because of the yard's diversification.

Although there is a pervasive influence of government regulations associated with the building of military ships, shipbuilders can do much within the current system to simplify operations. There is a tendency to build complicated organizations to implement complicated regulations. Simple organizational and procedural solutions would come closer to the business practices required for competition in the international market. Likewise, the government (principally the U.S. Navy) can do much within the existing FARs to reduce the requirements for shipbuilders and, thus, help them simplify their business practices.

SYSTEM TECHNOLOGIES

The overall application of technologies to shipbuilding is categorized as system technologies. The emphasis is on the overall process, rather than on individual material transformation processes. The specific technologies considered in this report are design, process simulation, standards and standardization, computer-aided design/computer-aided manufacturing (CAD/CAM), yard layout, and mechanization and automation. The recommended improvements in the application of technologies are those needed to bring U.S. shipbuilders up to the level of technology application of the best foreign competitors.

Design

The subject of design was discussed above under Business Practice Technologies, especially the importance of the ship design process to marketing. Design will also be discussed under New Materials and Product Technologies, where the emphasis will be on developing new types of ship design for the market. The following discussion centers on the design process itself and on the importance of design for production.

In recent U.S. practice, naval-architecture functions have often been separated from the shipbuilding process. In general, there have been two kinds of relationships between naval architects and their clients: in one case, they are attached to the owner; in the other, to the shipbuilder. The latter relationship should be encouraged for the reasons explained earlier (see especially the section on marketing above).

The ship design process has become more computer oriented, with most computations and almost all drawing done today in an electronic format. However, various computer software packages have been developed separately, such as packages for naval architectural calculations of structural analysis and hydrostatics and for the numerical drafting of drawings. Several systems are being developed to ensure that all engineering calculations and other design information are drawn from a common database. However, such systems should extend beyond the design office. The database should originate in the conceptual design that is part of marketing and carry over into production to ensure a smooth flow of information.

As was touched on briefly above, the design process should be better integrated with production. In general, ships should be designed with producibility in mind if they are to be built at a competitive cost. Developing a common database for design and production can be a great help in this area because the communication between design and production is eased, and the designer is more easily able to produce information that is useful for numerically controlled manufacture.

A major weakness of modern user-friendly computer hardware and software systems is that it is too easy to substitute computer-calculated results for well-thought-out solutions arrived at by basic approaches using simple tools (like a hand calculator). Therefore, computer output results should be checked by capable engineers who can use their knowledge of basic technical relationships and empirical data to avoid incorporating poor, computer-generated answers into design solutions.

Process Simulation

Process simulation offers a way to analyze processes, identify bottlenecks, and make cost-effective improvements. Often in manufacturing, relatively simple simulations can make a big difference. Process simulation can help overcome deficiencies of layout, particularly in older yards, where basic arrangements and boundaries are set. These yards may also be short of capital; therefore, major process improvements must be made with few dollars.

In assessing proposed production methods, it is important not only to consider the stage of the process to which they are directed but also to consider fully the possible effects of the proposed process changes on upstream and downstream activities. Changes can be selected and sequenced to achieve minimum disruption.

Process simulation can reveal which processes have no value to the customer, and these processes can be eliminated. Process simulation can also help organize the firm around process flows instead of around functional departments or activities of no value to the customer. Simulation is being used by some foreign shipbuilders to design automation improvements.

Of the six system technology areas surveyed by the committee, process simulation must receive the highest priority, for it gives structure to all the other efforts to improve the competitiveness of U.S. shipbuilders. This technology could also take advantage of U.S. expertise in computer simulation. Both defense and nondefense computer simulation in the United States are well advanced and are as good or better than in any other competitor nation. The United States can also apply technological expertise in product simulation to design and marketing.

As in other modeling, an incremental approach should be used to develop the optimal simulation of shipyard processes. The architecture of the simulation could be designed up front, and the development of subsequent modules could represent stages of the production process refined through successive approximations. Experience has shown that too much simulation can be undertaken at one time. Failure to refine a model by adequate intermittent empirical tests can lead to an expensive failure.

Standards and Standardization

Shipbuilders must work to reduce the complexity and variability of processes. The benefits are not only lower costs but also higher quality, greater reliability, less maintenance, and more precise tolerances. With standardization, the resources and scheduling for production are predictable, and processes can be managed; contract bids can be rationally estimated; and inventories of spare parts can be reduced. Standardized production processes also allow for continuous improvement because problems of stable processes can be analyzed.

Stability of processes is essential to worldwide competitiveness in the shipbuilding industry today. Standardization has provided the basis for the productivity of Japanese shipbuilding and for other industries internationally, including automobile and aircraft manufacturing. (Japanese shipbuilders have communicated important principles of manufacturing control to their main suppliers as well—another factor to which their success has been attributed (see Storch et al., 1994).

Traditional U.S. shipbuilding processes are exceptionally unstable, involving a lot of rework and disrupted schedules. Problems of outdated production processes have been exacerbated by the almost exclusive emphasis in the United States in recent years on producing military vessels. Even with batch production of these ships, there has been much expensive customization, and many engineering changes have been requested after orders were placed.

Standardization can be usefully carried out in a variety of areas, including: parts; ship designs; working methods and related operator training; and through the use of administrative procedures to control changes made or other variability in parts or working methods. (Storch [1994] provides more detail.) Variety can often be effectively produced with little or no loss of performance and at lower cost, with faster delivery and higher quality, by offering limited sets of standardized options. This strategy is used successfully by the automobile industry, as well as by other shipbuilders. Without standardization, the use of such technologies as CAD/CAM, modern robotic welding systems, or the International Standards Organization (ISO) 9000 quality management code are unlikely to produce notable improvement.

A metric to measure improvement in this area might be the number of distinct parts. Other industries have sought 30 percent reductions in the number of parts in given products or product lines. Shipbuilders need to develop similar goals. For example, engineers should be given incentives to use established part designs instead of developing new ones. (Storch et al., 1994, reviews various metrics for assessing production processes [pp. 76–81].)

The U.S. Coast Guard has been addressing the important related subject of harmonizing U.S. Coast Guard regulations with international standards, an extremely valuable contribution to increasing the efficiency of U.S. shipbuilding. The U.S. Coast Guard is now responsive to reducing or eliminating rules and regulations and to changing Coast Guard practices to follow international guidelines. (ISO efforts are now working through the International Maritime Organization on this development.) These changes will make it more acceptable to use foreign equipment. Committee members estimated, for example, that in recent years foreign component vendors have charged a premium of about 15 percent for procurement to U.S. Coast Guard requirements, a value considered a "fear plus opportunity factor." Another advantage of using international standards is that the need for translators and the errors they can introduce is eliminated.

International standards also represent true commercial standards for products made for the commercial market. This is in contrast to some U.S. commercial standards, which are actually converted military specifications that do not represent items intended for use on commercial ships. The use of international commercial standards by U.S. shipbuilders not only ensures acceptable international quality but can also help support a domestic industry of suppliers.

U.S. shipbuilders must adapt to the metric system to efficiently produce both military and commercial ships. Procurement on the international market, which offers only metric parts, will be required for commercial ships and could, at the same time, provide commercial/naval consistency in the production of new U.S. Navy ship designs.

COMPUTER-AIDED DESIGN/ COMPUTER-AIDED MANUFACTURING

An integrated CAD/CAM system, properly used, can make material acquisition, design, and construction faster and automate much of the design effort. CAD/CAM also drives processes toward standardization. But without improvements in process flow, material acquisition, and standardization—without reengineering the firm first—CAD/CAM methods cannot provide these benefits. U.S. shipbuilders are generally as well equipped in this respect as their competitors, although they are behind the most advanced yards in the world. Continuing normal evolution should keep U.S. shipbuilders competitive in CAD/CAM technology.

The value of CAD/CAM is only partially realized because standardization is inadequate, and capital to upgrade is not consistently available. However, evolutionary upgrading of CAD/CAM systems should continue. For CAD/CAM systems to offer their full potential, greater emphasis should also be given to the standardization of parts, design standards, and process standards.

Yard Layout

Most, but not all, U.S. shipyards were built decades ago to suit the needs of vastly different ships than the ones in demand today. Little can be done to change the boundaries and configurations of these yards. Through process simulation, however, bottlenecks in the work flow can be identified and offset by investing in process improvements. Because the geography of U.S. yards is largely frozen, process simulation becomes that much more important in assessing the value of specific capital investments. Without process simulation, managers tend to invest in more obvious measures, such as large cranes, when simpler and cheaper improvements may be more cost effective. Storch et al. (1994) observe that the greatest impacts on productivity come from emphasizing the development of efficient processes that are statistically under control.

Proposed changes in yard layout or other facilities must be carefully assessed for downstream and upstream effects as well as immediate effects, before proceeding. These changes should be undertaken using a team approach that includes facility personnel, design engineers, production planners/process control personnel, and material handling experts, as well as company consultant specialists, to analyze the production throughput for optimum results and improvement. Meaningful productivity gains are most likely if the builder develops a team approach that includes input from a representative group of production workers.

U.S. shipbuilders might be able to eliminate large amounts of material handling by modifying layouts, but they should be able to compete in spite of their current constrained geography. Many foreign yards are just as constrained, but this is not a major obstacle.

Mechanization and Automation

Mechanization and automation include measures, such as mechanically linked assembly lines and robots, that reduce labor requirements and improve the quality and repeatability of processes. U.S. and foreign shipbuilders make similar use of mechanization and automation for panel lines. Advanced automation, with robot welding and assembly, offers opportunities for in-process monitoring of quality and production efficiency; the high cost, however, must be justified by high volume and high labor costs. On the negative side, automation and mechanization tend to reduce flexibility. Their use will also be limited by the fact that U.S. shipbuilders will probably be producing very small lot sizes for the foreseeable future.

SHIPYARD PRODUCTION PROCESSES TECHNOLOGY

Shipyard production processes include the processes, equipment, planning, and other activities used to transform purchased materials, such as raw steel plates, structural shapes, components, and systems, into completed products. Many of these processes are required to build a ship, including fabrication, assembly, outfitting, erecting, and testing and their associated functions, such as material handling and painting.

For this study, the shipyard production processes of material handling, accuracy control, steel fabrication, block assembly and erection, outfitting, blasting and coating, and testing were investigated for the application of technology compared to foreign yards and for potential impact on the international competitiveness of U.S. shipbuilding.

Material Handling

The principal goal in material handling is that the material be available when the worker needs it and preferably not before. Material handling encompasses not only equipment but also the logistics and planning needed to obtain and move the material. The items handled in a shipyard vary in size from piece-parts that can be handled manually to large ship sections that weigh more than 1,000 tons.

The specific types of material-handling equipment are dependent on the specific yard and its products. Thus, material-handling costs, problems, and opportunities are unique to each yard, depending on layout, facilities, process flow, product, and ability to eliminate unnecessary handling through effective planning. However, material handling is in general a significant cost driver in ship construction.

One means of material handling is using large cranes for moving large assemblies. During the 1970s, there was increasing emphasis on installing larger crane capacity to lift the larger subassemblies and modules being produced in building ships. With the subsequent production of even larger modules and blocks, new material transporters that go under the blocks, support them at many points, and move them while only lifting them slightly have been emphasized.

Clearly, yard facilities must be able to support the erection of blocks into the dock. "Even with the constraints of existing shipyard layouts, it has been found that ground-level transport systems require less capital investment than increased-lift-capability cranes. Also, all the non-value-added work that is necessary for heavy lifts, such as padeyes, temporary strengthening, is eliminated, and productivity is improved . . . . The need for increased berth cranage capacity to handle the larger blocks can be avoided by assembling complete 'ring blocks.' The superstructure/deckhouse and possibly main engine would then be the determining factors for the capacity of the berth cranage" (Storch et al., 1994).

The other aspect of material handling is controlling numerous small parts, such as brackets and pipe hangers, that make up the larger assemblies. Most U.S. shipbuilders today use bar codes to identify parts. Although the use of bar codes could be improved, the competitive impact of this improvement would be small.

It is less important that U.S. shipbuilders spend large sums on new material-handling equipment than that they use what they have more efficiently. Although

U.S. shipbuilders are not the most efficient in handling materials, they are not at a major disadvantage using cranes and transporters. The best opportunities for U.S. shipbuilders in material handling are in up-front planning, reducing the quantity of parts, streamlining processes, and developing more effective sourcing and building strategies.

Accuracy Control

Accuracy control is the ability to regulate dimension as a management tool for continuously improving productivity. Without accuracy control, interim products will not fit together as designed, resulting in loss of the savings from in-shop construction and equipment package development.

The technique of group technology as applied to shipbuilding means building a block or unit of the entire ship at one time and in one location, with the piping, ducting, painting and the like done by a single crew. The advantages of group technology include lower labor and material handling costs because a large amount of work can be done in one location. For the advantages of group technology to be fully realized, however, shipyards must have advanced accuracy control systems so the separate pieces will fit together properly with a minimum of rework.

There are two kinds of accuracy control: dimensional process control and statistical process control. Dimensional process control is the process of predicting distortion during welding so that parts can be cut and shaped to the correct dimensions. Statistical process control is the process of measuring dimensions during production to ensure that needed tolerances are met.

These techniques are critical to building large ship sections without trim or distortion. (Trim and distortion are not desirable because of unnecessary material costs and the high cost of trimming and straightening the sections.) By using accuracy control techniques, some foreign yards are building "neat" units, that is, cutting steel to final dimensions without the accompanying material waste or the need for final trimming during assembly.

The general level of application of accuracy control by U.S. shipyards today is low in comparison to many foreign shipbuilders. A large financial commitment is not required to implement an accuracy-control program. Rather, strong management commitment and understanding are required.

Steel Fabrication

Fabrication is the process of cutting steel plate and shapes to correct dimensions, then welding individual pieces together to form a larger assembly. The state of the art is to use electronic design data to drive numerically controlled (NC) equipment in cutting steel plates and structural shapes (without curvature).

U.S. shipbuilders compare favorably in flat plate burning: NC plate burning is essentially standard practice in all U.S. yards.

There are no major differences between foreign and U.S. yards in rolling/forming plates, except in the use of line heating, which is used in many foreign yards but is not commonly used in the United States. U.S. yards are behind in the application of technology for automated cutting and prepping of structural shapes (e.g., bulb flats, T's, flat bars). Only one U.S. shipbuilder is known to have an automated profile line (funded under Manufacturing Technology Program [MANTECH]).

Block Assembly and Erection

The terms "block" and "unit" are often used interchangeably to describe the basic building blocks for erecting a ship in the dock. These units consist of the fully painted steel structure of a portion of the ship, with most piping, wiring, equipment and machinery installed. After welding the structure of the unit together in a fabrication shop, the units are transported to an assembly shop where the outfitting is performed. Then the units are transported to the building dock to be joined with other units of the ship.

To shorten build times, increase throughput, and make effective use of the drydock, shipbuilders should concentrate on producing optimally sized (not necessarily the largest) erection blocks (Storch et al., 1994). U.S. shipbuilders are behind in this area of production technologies, particularly in the use of automation in the fabrication of the steel structure.

Block size and erection process must be strongly linked. This is where it all comes together—accuracy control, build strategy, block size and scope, and outfitting.

Outfitting

Outfitting refers to the systems, equipment, and materials that go into a ship beyond the steel structure. Outfitting generally includes the material and labor for pipe and pipe hangers; electrical wiring, wireways, hangers, and the like; joiner work, such as cabinets, paneling, woodwork, and trim; machinery, such as pumps and valves; and painting. Outfitting is generally classified by location. Installation of components and systems early in the structural fabrication sequence is known as preoutfitting; work done after completion of erection, and especially after launching, is considered to be final outfitting.

The consensus of shipbuilders is that preoutfitting requires less labor than final outfitting. Components and systems can be installed on small units and blocks in assembly shops more easily than inside the structure of a completed ship. Final outfitting is generally more expensive because items must be carried to the ship and then to the location in the ship where they are needed. It is possible, however, to overapply preoutfitting and spend more to protect equipment during later assembly stages after it is installed than to carry it on board during a later stage of ship assembly.

U.S. shipyards that have produced large series of U.S. Navy ships have achieved a high level of preoutfitting skills. But without recent experience in commercial ship production, they may not be able to achieve the same degree of technological application as more-experienced foreign competitors who have been building series of commercial ships.

Proper outfitting requires extensive planning, as the thousands of items to be added to a ship along with supporting items must be at the correct location when they are needed. This planning requires a high degree of automation that links the design process with the production planning process. U.S. shipbuilders currently employ the same degree of technology as foreign builders.

Blasting and Coating

In all shipyards, surface preparation and painting are significant drivers in the cost of the ship. U.S. shipyard owners/operators are demanding (and receiving) high quality paint systems, because of the high cost of maintaining ships. Foreign shipbuilders have no major technological advantage in this area except the use of very large halls (buildings) where they can blast and coat large ship sections indoors.

A major problem in shipyards today is open blasting, which creates dust and raises environmental concerns. Other countries also have become or are becoming environmentally conscious, and open blasting is prohibited or severely curtailed. Thus, this does not necessarily put the United States at a competitive disadvantage.

Shipbuilders frequently order plate with a coating primer applied by the steel mill to prevent corrosion during transportation and storage. In other cases, the plate is blasted clean when it arrives, and a coat of primer is applied. In subsequent operations, stiffeners and webs are welded to the plates, and the plates are welded together. If the primer can be welded over without impairing the quality of the weld, the labor-intensive step of grinding off the primer is eliminated.

Currently, no shipbuilder anywhere has found a truly weldable primer that permits welding to be performed with no grinding or blasting beforehand. Although some welding processes permit the use of weldable primers, many others, particularly those involving high welding speeds, require that the primer be ground off to avoid contamination. The difference between the practice of U.S. shipbuilders and other builders worldwide is that many others have automated the grinding process. In addition, high production rates mean that assemblies do not sit outside for long periods prior to final welding, so there is not a large amount of rust to grind off. However, even if research produces a truly weldable primer, there will be little competitive advantage to U.S. shipbuilders because paint vendors will market their product worldwide.

Testing

The technology of testing is important to consider because U.S. shipbuilders, due to their focus on naval shipbuilding, are very sophisticated in testing when compared with competitor yards. However, the competitive value of this expertise is limited. U.S. shipbuilders will probably perform less testing on commercial ships because commercial products are much simpler and because, for commercial ships, considerations of price override quality considerations faster than for military ships. However, to the extent that quality is valued by international shipowners, a competitive advantage is available if testing is performed to international standards using U.S. methods.

NEW MATERIALS AND PRODUCT TECHNOLOGIES

Shipbuilding, like steel production and mining, is an industry in which a great deal of technology, both process and product, has matured. By evolutionary steps, traditional shipbuilding has moved to construction based on modules, mechanization, and now, automation. In the hierarchy of shipyard technology, know-how is the most valuable technology, worth vastly more in terms of dollars per ton than, say, mass-fabricated steel parts. The product strategy now followed in commercial settings is to concentrate on three to four products, using market research to determine which products to pursue. In price per unit, U.S. Navy ships represent the highest return. They are followed by specialized ships such as cruise ships, high speed ferries, and LNG carriers. Each market segment will require specific advances in ship design and product technologies.

For a successful marketing and research strategy, a shipbuilder must recognize the importance of both market pull and technology push, as well as differences between the objectives of owners and shipbuilders. Shipbuilders must sell customers what they need, namely, a "payload" that provides profits, such as the interior of a cruise ship rather than the traditional deadweight tonnage. Money invested by the shipbuilder should go where the payload goes as well as where the material and labor hour costs go.

The nature and value of automated ship design based on parametric data were described earlier in this chapter. These design tools encourage creativity in product design by allowing consideration of the greatest number of alternatives. At the same time, they provide fast estimates of weight and costs and a total economy calculation for each alternative design. Automated ship design is a fundamental product technology that U.S. shipbuilders must develop to succeed commercially. New design technology will need to incorporate appropriate concerns for producibility, environmental protection, and worker safety. Attention to producibility keeps labor costs down, whereas attention to environmental and worker safety keeps legal liability down.

New ship designs cannot be patented. A good ship design is the product of a good system engineering effort based on a good database of existing ship designs. It is not a single "new, better idea" that is patentable. Even "new, better ideas" for ship features are hard to patent enforceably in the global shipbuilding market—innovative ship designs are easily observed and copied. To establish and protect a position, a shipbuilder needs to make continuing improvements to any new ship concept and keep prices competitive. Some innovators believe that because of stronger U.S. laws, it is important to build in the United States to protect both patent and intellectual property rights.

Innovative shipbuilders face a challenge when trying to sell new products to very conservative shipowners, who will seldom pay more even for proven improvements and high performance. A variety of general factors may influence a shipowner's reluctance to adopt new products, including the inherent risks of new technology. Some owners do not want their fleets of ships to differ significantly from competing fleets. Also, some large shipowners may have an aversion to new designs because they reduce the number of common features in their fleets and introduce an element of risk in an established trade. At the same time, speed to market and uniqueness of products can be decisive in securing a competitive foothold. In short, selling new technology is challenging at best in this market of very expensive products.

Several questions need to be considered. Beyond the important area of automated ship design, which product technologies are likely to have the greatest impact on the competitiveness of the U.S. shipbuilding industry? How might these technologies be successfully developed and applied (including with respect to costs)? These questions will have different answers for different shipbuilders.

A wide variety of product technologies—ship designs, propulsion technologies, new materials, and other shipboard systems and components—might offer competitive advantages for U.S. shipbuilders. Table 2-1 shows a few selected areas of ship design and product technologies that the committee examined to gauge the current development for these technologies and their potential impact on and applicability to different segments of the shipbuilding market. Because of the different technology needs for different products and shipbuilders, product technologies could not be clearly ranked overall (nor could all potentially valuable technologies be examined). However, an attempt was made to rank the potential competitive advantages of technologies informally within five general categories, such as technologies for shipyard improvements, ship transportation systems, and so forth.

Particular competitive advantages in the technology areas identified would be seen if the following were developed:

- breakthrough design capability, which allows a new design to be developed, implemented, built and marketed before the competition can copy it;
- shallow water draft oceangoing ship designs for short-cut trade routes,

such as the Siberian Sea route between the north Pacific Rim and northern Europe;

- unstiffened curved plate technology, which can enable more automated production and longer lasting ballast tank coatings;
- automated cargo handling, including necessary dockside intermodal facilities (e.g., ship to truck/rail), with a time goal of unloading and distributing cargo in less than one shift (one to two hours is a conceivable goal, but distribution out of the harbor currently presents a bottleneck.);
- ten years or greater maintenance cycle for drydocking and classification special survey (implementation of such technology would be dependant on acceptance by regulatory agencies and classification societies.);
- reduced manning, as in a six-person or smaller crew, with one person stationed on the bridge (implementation of such technology would require changes by regulatory agencies.); and
- improved maintenance/manning balance, including an optimization between shore-based and shipboard maintenance, considering turnaround time in port (manning, port time, and maintenance are interdependent; the goal is to reduce all to an optimum point).

Potential Competitive Impact

The following brief review illustrates how a few of the technologies identified by the committee might offer U.S. shipbuilders critical competitive advantages.

Advanced Propulsion Technologies

Interest in new propulsion technologies is driven by the search for improvements over current slow-speed, direct-drive diesel engines. The main candidates—gas turbine and gas-turbine diesel or combined electric integrated propulsion systems—are relevant only to niche markets, such as LNG tankers, short-distance shuttle tankers, extremely environmentally friendly tankers, fast ships, and cruise ships. Other prospective propulsion types, such as fuel cells and permanent magnet motors, are worth pursuing partly because of potentially low environmental impacts and also because they might reduce manning requirements. Diesel electric drive systems cost $4 million to $6 million more than slow-speed diesels for shuttle and Suez max tankers and offer 6 percent less thermal efficiency. Thus, they are useful only for niche markets or where high priority is given to ship control for environmentally friendly operation. However, a higher-frequency generator operating at a higher speed would make this technology more attractive. With permanent magnet drives, a major problem is the large diameter of the motor and the high acquisition cost.

At present, there are few restrictions on burning low-grade fuel at sea.

TABLE 2-1 Ship Design and Product Technologies

Technology[a]	Technology Group[b]	Technology Type[c]	Technology Sophistication: Today	Technology Sophistication: 5-Year Goal
Improved producibility	1	E	Medium-Low	Medium-High
Commercial ship design tools/ technology	1	E	Low	Medium-Low
Protective coatings	1	E	Low	High
Breakthrough design capability	1	B		
Unstiffened curved plate tanker structure	1	B	Point	Design
"Fast ship" technology	2	E	Low	High
Cargo handling, including port and ship/terminal interface	2	E	Medium	Medium-High
Shoal draft	2	E	Medium-Low	Medium-High
Advanced propulsion systems	3	B	Medium	Medium-High

[a]Technology types listed by priority order as determined by the committee. Individual technologies listed within technology type by sub-priorities as determined by the committee.

[b]Technology groups:

1. Shipyard-product improvement/development
2. Transportation system requirement
3. Material supplier driven
4. Owner cost driven
5. Social issues driven: implemented through rules, regulations, insurance and litigation costs

However, the restrictions on emissions of pollutants in or near port are increasing and encourage the development of new propulsion systems.

An example of advanced propulsion plant technology applied to tankers is now being evaluated as part of a fiscal year 1994 ARPA MARITECH project. Overall ship design tradeoffs are being made between alternate designs of integrated electric propulsion and ship service power plants; conventional direct-drive, slow-speed diesel propulsion; and geared medium-speed diesel propulsion.

Competitive Impact		Technology Application					
Today	5-Year Goal	Crude Oil Tanker	Bulk Carrier	Container Ship	RO/RO	Fast Ferry	Cruise Ship
Medium-Low	Medium-High[d]	X	X	X	X	X	X
Low	High[e]	X	X	X	X	X	X
Medium-Low	High	XX	XX	X	X	X	X
				X	X	X	X
Medium	High	X	X	X	X		
Low	High[f]			X	X	X	X
Medium	High[g]			X	X	X	
Low	High		X	X	X		X
Low	Medium-High			X	X	XX	XX

[c]Technology types:
1. Evolutionary—incremental changes in the immediate future
2. Breakthrough—successful implementation will cause major changes

[d]Includes structural design for automated construction and extensive use of ship component and material standards.

[e]Design is only 5 to 10 percent of commercial shipbuilding costs. However, a bad design will be costly to build, operate, or to rebuild to correct.

[f]Here is an area where experience with U.S. Navy ships and technology form a good high speed commercial ship base.

[g]Turnaround of a large ship in less than eight hours, preferably less than four hours.

Initial results of the studies indicate a more compact electric propulsion plan that permits use of a larger portion of the hull to carry cargo than do the non-electric drive alternatives. Ship control and maneuvering are superior, and electric plant/ propulsion plant system redundancy greatly increases the environmental friendliness of the ship (backup for failed systems or components). The speed potential is also increased, as are potential revenues and the ability to make up for weather or scheduling delays.

TABLE 2-1 Ship Design and Product Technologies (continued)

Technology[a]	Technology Group[b]	Technology Type[c]	Technology Sophistication Today	Technology Sophistication 5-Year Goal
Composite materials design, test, and certification				
A. GRP Structure	3	E	Medium-Low[h]	Medium-High
B. Other Composite Structure	3	E	High	High
C. Composite Machinery	3	E	Low	Medium
Reduced manning (≤6)	4	B	Medium-Low	Medium-High
Advanced ship management and control	4	E	Medium	High
Improved maintainability	4	B	Medium-Low	Medium-High
Improved environmental "friendliness"	5	E	Medium-High	Medium-Low
Improved worker safety	5	E	High	Medium-High

[a]Technology types listed by priority order as determined by the committee. Individual technologies listed within technology type by sub-priorities as determined by the committee.

[b]Technology types:

1. Shipyard product improvement/development
2. Transportation system requirement
3. Material supplier driven

A vital developmental issue is presented by the U.S. Navy's development of new power plants. Wherever possible, commercial systems should be adopted for Navy use rather than developing independent Navy systems that are too complex and expensive for commercial purposes. The U.S. Navy should buy engines off the shelf to achieve significantly more affordable ships and to help support a broad industrial base. Committee members and workshop participants felt strongly on this subject, which is addressed in greater depth in Chapter 3.

Ballast Tank Protective Coatings

Another technology area that may have major competitive impacts is ballast tank protective coatings. Cleaning and recoating (painting) ballast tanks has

Competitive Impact		Technology Application					
Today	5 Years	Crude Oil Tanker	Bulk Carrier	Container Ship	RO/RO	Fast Ferry	Cruise Ship
Medium-Low	Medium-High			X	X	X	X
Medium-Low	Medium-Low			X	X	X	X
Low	Medium-Low			X	X	X	X
Medium-Low	High	X	X	X	X	X	X
Medium	Medium	X	X	X	X	X	X
Medium-Low	Medium	X	X	X	X	X	X
Low	Low	X	X	X	X	X	X
Medium-Low	Medium	X	X	X	X	X	X

4. Owner cost driven.
5. Social issues driven: implemented through rules, regulations, insurance and litigation costs

[c]Technology types:
1. Evolutionary—incremental changes in the immediate future
2. Breakthrough—successful implementation will cause major changes

[h]Behind Europeans, ahead of Far East. U.S. is hindered mostly by regulations.

always been a messy, expensive job. But with new environmental and safety regulations, it has become an extremely expensive maintenance function, and shipowners are looking for coatings that will last 10 or 15 years or longer. For handy max-size and larger tankers, a ballast tank cleaning and recoating job can cost up to $10 million; it thus becomes the largest cost item of the five-year inspection survey. The double-hull tanker configuration makes the job even more difficult. Moreover, recently instituted human health and environmental regulations for shipbuilding make blasting and painting even more expensive than they have been in the past.

Extending the life of ballast-tank coatings does not mean simply buying better paint and applying it more carefully. The life of the coating is affected by the configuration of the steel structure and the quality of the steel fabrication process.

Coating breakdown and resulting corrosion begin at the inside and outside corners of the structure. Paint doesn't stick well to sharp edges or crevices; therefore, a double-hull ballast tank structural design needs to be developed that will minimize total stiffener structure length and associated welding length. Exposed plate edges that are clean and without sharp corners and that have no weld splatter lengthen the life of coatings, and their use is becoming standard practice by many foreign shipbuilders.

Tanker construction technology that uses unstiffened curved plates is potentially valuable because it accomplishes several goals and reduces the costs of the shipbuilding process. The unstiffened-curved–plate construction technology increases coating life in a ballast-tank structure built in standard cells welded together in standard double-hull sections. These sections can be hermetically sealed and automatically blasted and painted in a controlled environment without contact by shipyard workers. The internal structure is relatively smooth, with minimum stiffeners, because of the inherent stiffness of the curved plate. The result is low-cost, long-lived coatings that may last more than 20 years, if they are not damaged during ship operation.

The unstiffened-curve–plate technology potentially provides an excellent example of systematic, joint product-and-process technologies that should be developed and applied by U.S. shipbuilders to other types of ships and ship features.

SUMMARY

This chapter has considered the technologies employed in shipbuilding and how the application of those technologies must be improved for U.S. shipbuilders to become commercially viable in the international shipbuilding market. Business processes in particular must be changed, including marketing, bidding and estimating, sourcing, and management systems. Additional investments will be needed in system technologies, production processes, and product design. In some cases, significant capital investments will be needed to improve efficiency. Table 2-2 summarizes each of the four technology categories important to the commercial competitiveness of the U.S. shipbuilding industry.

The priorities of Table 2-2 are based on the judgment of committee members of the importance of each technology area and the status of U.S. shipbuilders in each area relative to foreign competitors. A more comprehensive study could define the U.S. shipbuilding industry's current capabilities for building commercial ships of various types and capacities in terms of construction time; design and engineering labor requirements; nonrecurring labor, recurring production labor, and direct material costs; general requirements cost; and overhead expenses. Construction time could be broken down into two periods: (1) contract signing to start of construction (cutting steel) and (2) start of construction to delivery. The capability of U.S. shipbuilders with the leading international performance levels

TABLE 2-2 Priorities for Technology Investment

Technology	Status	Priority
Business process technologies	Very much behind, especially in marketing, costing, sourcing, and management systems; need to buy materials on the world market	Most important; urgent for marketing
System technologies	Somewhat behind, particularly in process simulation and standards	Middle priority
Shipyard production process technologies	Behind in material handling, accuracy control, and in block assembly and fabrication, although not desperately in any one area; primarily need to apply best practices; little new technology needed	Less important
New materials and product technologies	Behind in design for the world market	Varies by market segment

could then be compared for each element. This framework for evaluating the different technologies would provide another perspective on the assignment of priorities.

Clearly, improvement is needed in all areas, and improvements in one area cannot occur in isolation from the others. Business-process technologies require significant attention by the U.S. shipbuilding industry, and marketing strategies must be developed; but it is difficult to secure a sale without competitive price and delivery schedules. However, improvements in production processes cannot occur in isolation; they must be part of a total manufacturing process, which requires contracts for ship production.

The current marketing strategy of many U.S. shipbuilders of awaiting requests for proposals from either the government or private shipowners is changing to a strategy of actively pursuing commercial contracts at home and abroad. However, shipbuilders are hampered by the lack of market information, poor customer relationships, the inability to respond rapidly to customer needs, and the general lack of predesign capability, standard designs, established reputations, and general marketing expertise. Improvements in all of the above areas are necessary if U.S. shipbuilders are to become internationally competitive. However, because these are factors that relate mostly to individual shipbuilders and only to a small extent to the U.S. shipbuilding industry as a whole, improvements will have to come from individual shipbuilders improving their own capabilities.

Shipyard cost-estimating procedures today use a ship-systems–based approach rather than an activity-based approach in alignment with emerging production practices. The influence of government procurement requirements currently hampers a change. U.S. shipbuilders require expertise in rapidly developing parametric designs and associated cost estimates to suit customer needs. Automated design systems can be a great help in this area.

Current procedures used by most U.S. shipbuilders for sourcing materials and components are based on compliance with the procurement requirements imposed by the U.S. Navy. These requirements have brought about distant relationships between shipbuilders and their suppliers rather than cooperative relationships based on mutual trust. Developing better relationships with suppliers, changing from requesting multiple bids to material control, and working directly with suppliers on product development can reduce procurement time, reduce rework, and reduce costs. Many suppliers for shipbuilding components are overseas, so U.S. shipbuilders must extend their sourcing capability worldwide, including development of multilingual skills. Methods of sourcing components are tied to a shipbuilder's marketing niche strategy and to developing a working relationship with vendors who specialize in that market.

Engineering capability in most U.S. shipyards has been developed to meet the needs of detail design of U.S. Navy ships rather than the precontract and contract designs of commercial ships. The training U.S. shipyard workers have received to achieve the high quality of workmanship required for U.S. Navy ships, however, is compatible with the quality now required by some commercial owners and classification societies. The greatest need may be for management to convert from government-procurement-based practices to international-commercial management practices.

Information management systems are required that are integrated with a shipbuilder's various cost, accounting, labor, design, scheduling, and production systems. These systems should include the capability of using simulation to predict the effect of changes before they occur. In addition, these management systems must support both government and commercial needs if shipbuilders intend to produce ships for both markets.

From the standpoint of system technologies, a design process that is consistent with international competitive standards should be capable of developing a database to describe the ship during conceptual design and should continue to use and build on that same database throughout shipbuilding stages to production and delivery of the ship. This type of design process is not only more efficient in transfer of data; it also helps to ensure that the design best accommodates the needs of production.

In the transition to commercial shipbuilding, U.S. shipyards are acquiring and developing new production methods. Efficient planning for the adoption of these methods can be made through the capability of process simulation. This capability is especially important in shipyards with limited space so as to obtain the best yard layout for production.

Standardization of parts and production processes can both reduce price and improve quality. Standardization can encompass not only overall ship design but also standard components between different ship designs. Adoption of international standards by shipbuilders for parts and materials will assist with commercial marketing of ships.

Increased use of CAD/CAM is seen today in most U.S. shipyards. Full realization of the benefits of these processes requires concurrent improvements in other technologies, such as process flow, material acquisition, and standardization.

Shipyard layout can present difficulties, especially where space for production facilities is limited. However, many successful foreign yards have the same problem. The use of process simulation to investigate the effect on production of changes in yard layout is an important tool for overcoming the difficulties of limited space.

U.S. and foreign shipbuilders currently employ the same level of mechanization and automation of production processes. The most advanced systems have been developed for foreign shipbuilders, and the developers of these systems are selling them to U.S. shipbuilders.

Material-handling technology within U.S. shipyards today is about equal to world class standards, with the exception of large transporters, in which some foreign yards have greater capability. The area that needs the most improvement is logistics. Improving logistics will reduce the amount of material to be moved.

Accuracy control in shipbuilding can be improved through better application of dimensional process control and statistical process control. A commitment by management to enforcing production standards is required for in-process work and the final product.

A major improvement in steel fabrication in most U.S. shipyards would be the use of automated profile cutting and preparation equipment. Likewise, U.S. shipbuilders do not apply the same degree of automation in the production of structural units of the hull structure as foreign competitors.

The level of technology application in the United States for outfitting and preoutfitting U.S. Navy ships is the same as that in foreign shipyards for commercial ships. The automation of design and production planning are not at the same high level to support fully the outfitting process.

Blasting and coating of structures in the United States is not usually performed in large halls that many foreign shipyards have. No primer for steel available today is capable of being welded-over under conditions of high-productivity welding. Robotic grinding of primers prior to welding is also not practiced by U.S. shipbuilders as it is abroad.

The expertise in testing that U.S. shipbuilders have gained from naval shipbuilding will be of little advantage in commercial production.

Improvements in product technologies or facilities do not reveal any new technology that will give U.S. shipbuilders a tremendous competitive edge over foreign shipbuilders. As will be seen in the following chapter, the primary emphasis in government programs is on developing product technologies intended to improve the capabilities of shipboard systems. The real need is for improved design capability, so that when new concepts and products are developed, they can be moved into production quickly. Continuous innovations can provide a competitive edge.

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3

Programs to Increase the Technological Competitiveness of U.S. Shipyards

INTRODUCTION

This chapter assesses current and proposed programs that invest in ship design and production-related research and identifies appropriate changes that might improve contributions to an internationally competitive U.S. shipbuilding industry. Federal programs to aid the U.S. shipbuilding industry can be classified as either financial or technological. Historically, financial programs, such as subsidies for construction, have been the principal means of helping U.S. commercial shipbuilders compete with foreign firms. In the early 1980s, however, such programs were cancelled by President Reagan, and emphasis was given by the administration and the yards to reinvigorating the U.S. Navy fleet. As of 1994, U.S. shipbuilding firms had not contracted for an oceangoing vessel for world commerce in more than a decade. Most shipbuilding research had been funded by the Navy, and it addressed issues unique to naval ships. Within the past two years, with declining defense budgets, U.S. government assistance to the industry has taken the form of government-industry R&D partnerships. (Chapter 1 outlined the history of U.S. government shipbuilding assistance programs in greater detail.)

This chapter evaluates selected recent and proposed federal and joint government-industry programs:[1] ARPA's MARITECH program, Technology

[1]Significant programs relevant to the technology of commercial shipbuilding were identified and selected for evaluation based on the knowledge of committee members and Marine Board staff, extensive information provided to the committee by government liaisons, and subsequent interviews with program managers.

Reinvestment Project (TRP), and Simulation-Based Design (SBD) program; the NSRP program; the Navy Manufacturing Technology Program (MANTECH) and its spinoff, the Navy Best Manufacturing Practices (BMP) program; the Naval Sea Systems Command's (NAVSEA) Sealift Ship Technology Development Program and Affordability Through Commonality program; the ONR Surface Ship Technology Program; standards activities, including those of the American Society for Testing and Materials (ASTM) and the ISO; and the MARAD National Maritime Resource and Education Center. Information about these programs was provided through written documentation, briefings from program managers and others, and the experience of committee members. Of these programs, only MARITECH is specifically intended to assist U.S. shipbuilders in becoming internationally competitive. However, the committee assessed all related programs to determine the extent to which they contribute toward that objective. The principal objective of the committee's assessment of the programs was to look at their overall objectives and their intended results. A detailed program review of the actual performance of the programs toward achieving stated goals was not made. The question asked was "If the programs met their goals, would they make a difference?" (Appendix D further details these programs.)

As chapters 1 and 2 showed, the challenge to shipbuilders will be substantial for the next decade. For the next five to ten years, U.S. shipbuilders will almost certainly lag behind foreign world-class competitors on the combined basis of overall cost, material availability, and delivery schedule because of the great differences between the methods and circumstances of foreign and U.S. shipbuilders.

Chapter 2 concluded that for U.S. shipbuilders to become commercially viable on a cost basis their business processes must be changed, including marketing, bidding and estimating, sourcing, and management systems. Labor forces will also need to be reduced under any likely forecast. Additional investments will be needed in system technologies, production processes, and product design. In some cases, significant capital investments will be needed to improve efficiency. Table 2-2 summarized these findings for each of the four technology categories important to the commercial competitiveness of U.S. industry.

The following sections assess shipbuilding assistance programs. Each program is considered for implications in the four technology areas shown in Table 2-2. Care has been taken in the evaluation to consider program goals and accomplishments in view of the mission and structure of each program. Some of the programs covered below are strongly oriented to defense applications, some seek secondarily to achieve commercial benefits (e.g., via a dual-use orientation), and some are targeted specifically at commercial advances. These differences are appropriately taken into account.

MARITIME SYSTEMS TECHNOLOGY AND THE TECHNOLOGY REINVESTMENT PROJECT

In March of 1993, President Clinton announced a new set of technology initiatives to integrate defense and commercial industrial bases in the post-Cold War era. The TRP was to be the primary vehicle for promoting dual-use technologies to pursue this goal. TRP is overseen by the Department of Defense's ARPA, although most of the contract awards are administered by other government agencies, both within and outside the Department of Defense. TRP awards were to be made on a competitive basis and were to target a set of technology areas that would change each year. In the first competition, TRP focus areas included shipbuilding, and of the 212 awards totaling $470 million, two (representing a total of $23.7 million) were made to shipbuilding.

The MARITECH program, begun in 1993, is structured much like TRP but is aimed exclusively at shipbuilding. MARITECH is funded separately from the main TRP program. The program has as an independent focus area with its own line item in the federal budget. MARITECH funding was $30 million in fiscal year 1994 and $40 million in 1995; the administration has called for $50 million per year for fiscal years 1996 to 1998.

MARITECH and TRP projects are innovative public–private partnerships. They have several critical characteristics:

- They fund technology applications and demonstrations that are expected to find commercial uses within two to five years after completion. Development of new technology applications and transfer of foreign know-how to U.S. yards are both encouraged.
- They are based on government-industry collaboration, and at least one-half of a project's resources must come from the private-sector partner. There is duplication of effort (up to five teams in the overlapping area of 40,000-DWT tanker design), and the immediate effort is to help individual teams, not the overall shipbuilding industry.
- Funding is awarded based on an open competition that is outside the FAR process and can use new government agreements that allow flexibility in "contracting" to reduce the complexity of the program. This strategy also allows key information developed to remain proprietary.
- They require that proposal teams be vertical alliances of shipbuilders and other interested industrial partners.

As of March 1995, the TRP and MARITECH programs together have awarded $49.5 million in funds for 22 separate projects that are applicable to shipbuilding. Money was awarded to the teams—which usually inculded one U.S. shipyard—that were "most effective in identifying a real market need, an innovative design concept to service that market, and a competitive approach for the detailed design and construction process that could be implemented in the near

TABLE 3-1 MARITECH and TRP Projects, by Primary Technology Area

	Business Process Technologies	System Technologies	Production Process Technologies	Product Technologies	Other
Number of projects addressing the technology area	2	1	2	17	0
Dollar value of projects ($1,000)	$4,600	$1,600	$14,500	$28,800	$0
(% of total dollars)	9%	3%	29%	58%	0%

term." The cost-match from private-sector participants allowed the inclusion of in-kind contributions, so the overall cash outlays the programs represent are actually twice their reported dollar amount. The first MARITECH projects were completed in the fall of 1995.

Tables 3-1 and 3-2 show how the 22 TRP and MARITECH projects address the four technology areas examined in Chapter 2. Table 3-1 shows the projects by primary technology area, and Table 3-2 illustrates the degree to which projects may have more than one technology-area goal. Thus, in Table 3-2, projects are counted in more than category, as appropriate, and the dollar values for individual projects are distributed among the various technology areas they address, according to available project documentation.

Although MARITECH is quite young, several observations can already be made about its approach. First, MARITECH is funded at a scale significant enough to make a genuine contribution to the industry's development if the program is well designed and carried out. Second, MARITECH is directed at areas that the committee believes have some commercial importance, including the area of business processes and technologies. Even those projects that address product technologies have the purpose of ship design for marketing rather than for development of enhanced system capabilities. MARITECH also supports the teaming of experienced foreign yards and U.S. yards. This should allow the transfer of valuable experience to U.S. builders, for example, with regard to doing business with worldwide suppliers. Finally, MARITECH encourages industry investment and other market-shaped industry activities. In short, MARITECH appears to be well designed to support other government and private efforts to help the U.S. shipbuilding industry reenter the international commercial market.

The program is structured so that shipbuilders invest as much in the program as the government does in anticipation that, because they are spending their own funds, shipbuilders will only do work important to them and that they will

TABLE 3-2 MARITECH and TRP Projects, by Both Primary and Secondary Technology Areas

	Business Process Technologies	System Technologies	Production Process Technologies	Product Technologies	Other
Number of projects addressing the technology area[a]	8	6	6	20	0
Dollar value of projects ($1,000)	$10,080	$6,560	$7,200	$25,660	$0
% of total dollars	20%	13%	15%	52%	0%

[a]All projects that address the technology area, whether primarily or secondarily, are counted for that technology area. The actual total number of projects is 22.

implement the results of the research in their efforts to become internationally competitive. Investment by the government in MARITECH should be considered a temporary effort to encourage shipbuilders to invest their own funds in technology development. Additionally, some critics of the program question spending public funds to develop proprietary information in projects that sometimes reflect a duplication of effort. The proprietary nature of the program has the advantage of encouraging industry participation in individual projects, but it does not encourage joint efforts between shipyards to improve the total health of the U.S. shipbuilding industry. There should be significant results from individual projects that can be of benefit to all shipbuilders but would not compromise the originating shipbuilder's competitive position. These results should be made available to all U.S. shipbuilders, perhaps in a cooperative forum, such as the NSRP (discussed below).

In addition to the programs for MARITECH and TRP, ARPA has a program on simulation-based design aimed at developing a system to integrate the resources of ship design and acquisition in real-time to improve both ship design and construction processes. This program is funded for $70 million over a six-year period. The program is intended to contribute to the important area of business processes; however, with regard to shipbuilding process simulation in particular, such modeling is better and more easily developed in incremental steps based on current business processes, than as a single, massive computerized system.

NATIONAL SHIPBUILDING RESEARCH PROGRAM

The NSRP is another federally funded but industry-directed effort. The 1970 amendments to the Merchant Marine Act of 1936 directed MARAD to establish a collaborative program with the U.S. shipbuilding industry as an efficient way to develop and maintain a competitive industrial base for national security. During the 1980s, the program was funded by the U.S. Navy; currently, funding is provided by ARPA. In the 1980s, NSRP's objective was to reduce the cost of naval ship construction. In the 1990s, NSRP's mission evolved to helping the U.S. shipbuilding and repair industry achieve and maintain global competitiveness in quality, time, cost, and customer satisfaction.

NSRP operates under the auspices of the Society of Naval Architects and Marine Engineers (SNAME), under whose bylaws firms can meet and address shared technical concerns in an environment free of antitrust constraints. Currently, NSRP comprises eight panels: facilities and environmental effects; surface preparation and coatings; design/production integration; human resource innovations; marine industry standards; welding; industrial engineering; and education and training.

Annual funding for the NSRP has not been steady. From 1982 to 1984, government provided more than $4 million annually—a figure that dropped to as low as $0.5 million in 1988. Recently, funding has increased, with $2.8 million in 1994. To date most research funds have been used to catch up to foreign competitors rather than to gain a competitive advantage. NSRP projects always have a public summary (although details may be withheld on a proprietary basis by researchers). One feature of conducting the work under government contracts is ensuring that program results are placed in the public domain. Placing information in the public domain, however, also makes it available to international competitors. In fact, Spanish shipbuilders have cited NSRP technology as important for their reentry into the international shipbuilding marketplace (Sarabia and Gutierrez, 1992).

Although the intent and accomplishments of NSRP are desirable, the funding level of the program constrains any significant contributions to the development of the U.S. commercial industry. Moreover, the recent emphasis has been largely on building U.S. Navy ships.

TABLE 3-3 MANTECH Projects, by Primary Technology Area

	Business Process Technologies	System Technologies	Production Process Technologies	Product Technologies	Other
Number of projects addressing the technology area	0	8	27	6	3
Dollar value of programs ($1,000)	$0	$9,960	$63,286	$12,923	$5,010
% of total dollars	0%	11%	69%	14%	5%

MANUFACTURING TECHNOLOGY PROGRAM

The U.S. Navy's MANTECH program is intended to increase the reliability of Navy weapons systems, reduce their costs, and improve the responsiveness of the industrial base to Navy needs by means of joint efforts with defense contractors. Navy needs include risk reduction, technology development, the dissemination of dual-use technologies for commercial purposes, and the transfer of developed techniques and technologies to ongoing defense production. MANTECH has six centers of excellence. These are in the areas of automated manufacturing, composites, electronics manufacturing, metalworking technology, Navy joining, and shipbuilding technology.

The committee identified 61 current Navy MANTECH projects with applications to shipbuilding. Of these, 17 are judged by the committee to be structured for defense needs and have little application to commercial shipbuilding; 44 are judged to be relevant to shipbuilding for world commerce; four are judged to have high commercial potential (Appendix D). Projects relevant to commercial shipbuilding represent funding of about $90 million annually, although the projects are largely focused on naval applications, so the value to commercial shipbuilding has been limited. These projects cover such areas as intelligent welding, plasma spray using computer numerical control (CNC), automated propeller optical measurement, propeller adaptive machining, automated LAN-integrated paperless factory modernization, computer-integrated focused factory management, and computer-aided manufacturing system engineering.

Tables 3-3 and 3-4 summarize the emphases of the 44 MANTECH projects using the committee's analytical framework. Note that, like Table 3-1, Table 3-3 classifies projects only by primary technology area; and, like Table 3-2, Table 3-4 classifies projects by all identifiable technology area goals, distributing dollar

TABLE 3-4 MANTECH Projects, by Both Primary and Secondary Technology Areas

	Business Process Technologies	System Technologies	Production Process Technologies	Product Technologies	Other
Number of projects addressing the technology area[a]	3	8	27	6	20
Dollar value of programs ($1,000)	$650	$9,310	$63,786	$12,423	$5,010
% of total dollars	1%	10%	70%	14%	5%

[a]The projects address multiple technology areas, as here indicated. The actual total of these projects addressing commercial shipbuilding needs is 44.

values for individual projects among all relevant technology areas according to available project documentation.

The evidence indicates that MANTECH is not likely to be a significant contributor to the competitiveness of the U.S. shipbuilding industry—as indeed this program was not designed to be. The stated purpose of MANTECH is to support manufacturing needs to improve the nation's ability to provide affordable military equipment and to sustain that equipment cost effectively. Less than 1 percent of the program's total budget is devoted to business-process technologies, the area that needs the greatest development for the reemergence of a commercial shipbuilding industry. At the same time, it should be recognized, as was clarified in Chapter 2, that developing business-process technologies strictly by means of government support would be very difficult. Business technologies must be forged in significant part through actual competition in commercial markets (as is arranged to some extent, for example, in the MARITECH program). MANTECH clearly emphasizes production-process technologies, but the committee found that U.S. shipbuilders need the least improvement in that area.

BEST MANUFACTURING PRACTICES

In the BMP program, which was established and funded as part of the Navy MANTECH program, the objective is not to push the state of the art but rather "to identify the best practices used in industry, to encourage industry to share these practices among themselves, and to work together toward a common goal of high efficiency and improved product reliability." BMP is thus intended to identify and disseminate best industry practices to U.S. shipbuilders. Beyond encouraging the use of existing and newly developing technologies in a broad range of industries, from defense manufacturing industries to hotels, BMP provides "noncompetitive means to address common problems." To address the growing demand for BMP briefings, training, and information, four satellite resource centers are being established around the nation. One BMP project of particular note is the Program Manager's Workstation, an expert system designed to assist with program management, reduction of technical risk, and improved efficiency. This system could be classified as a business-process technology.

Although BMP originated informally under the MANTECH program, it is now funded separately for $4 million in fiscal year 1995; and $2 million is now budgeted annually for the program.

To date, however, no commercial shipyard has invited BMP to describe their practices. BMP may be judged successful in support of commercial shipbuilding in the event it affects yard management decisions to a productive end. At this time, the value of the program cannot be assessed. The BMP program has potential, but it is not currently structured to transfer foreign-yard practices to U.S. shipbuilders.

NAVAL SEA SYSTEMS COMMAND MID-TERM SEALIFT SHIP TECHNOLOGY DEVELOPMENT PROGRAM

The Strategic Sealift Technology Development Program is a broad based R&D effort managed by NAVSEA. The program goal is to develop new concepts and technologies that can be applied to future sealift ships and merchant ships to enhance their operational capability and efficiency while simultaneously reducing the life-cycle cost, particularly the acquisition cost, of ships capable of performing the sealift mission.

The technologies/developments addressed by the program include total ship concepts, alternatives for achieving quick convertibility of lift on/lift off cargo ships to roll on/roll off cargo ships and vice versa, improvements in ship production and design for production methods, better hydrodynamics, improved ship propulsion, equipment to increase cargo loading and unloading rates (including merchant ship replenishment), manning reduction concepts, improved structural configurations and materials, and logistics-over-the-shore (LOTS) improvements. The long-term efforts will also enhance Joint Service LOTS operations. This program heavily involves U.S. industry, particularly shipyards, and includes participation by the U.S. Coast Guard and MARAD to assure that the potential benefits of technologies to commercial ship design and shipbuilding are realized. The three primary focus areas are (1) mid-term sealift improvements (post 2000), (2) long-term improvements (2010–2020) and (3) a merchant-ship naval augmentation program.

The total appropriated and planned funding for this program for fiscal years 1993–1997 is about $55 million, less than 1.5 percent of the Sealift Ship Acquisition Program through fiscal year 1999. However, the projects are mostly in the area of new materials and product technologies, which are not critical to international competitiveness.

AFFORDABILITY THROUGH COMMONALITY PROGRAM

NAVSEA's Affordability Through Commonality Program is "committed to developing generic build strategies, new ship architectures, and working with industry to incorporate shipyard production processes into naval ship design." The objective is to design, build, and operate a fleet that is affordable within the constraints of future budget restrictions and that maintains standards of performance and reliability. In particular, the emphasis is on commonality, that is, the development of standard units that can be used in a variety of applications. The program's budget was $17 million for fiscal year 1995.

While this program appears to be worthwhile for defense goals, its almost exclusive focus on the Navy makes it generally inapplicable for commercial purposes. The standard units being developed, such as standard habitability modules for U.S. Navy ships, will have little commercial application. However, the element of the program using commercial, off-the-shelf equipment for U.S. Navy combat ships will strengthen the U.S. supplier base for commercial shipboard equipment.

OFFICE OF NAVAL RESEARCH SURFACE SHIP TECHNOLOGY PROGRAM

ONR has many projects for improving the performance and production of Navy ships that are applicable to commercial ships. Examples include projects on the advanced double hull, affordable composite structures, and advanced electrical systems.

Projects under the ONR Surface Ship Technology Program are generally targeted at technologies, such as composites and fuel cells, that will yield products for the next generation of ships, rather than for any segment of today's commercial shipbuilding market. Thus, although they are important to the Navy, these technologies are generally not critical for companies reentering the international commercial shipbuilding market. To date, none of these technologies promises breakthrough market penetration. As was stated in Chapter 2, any new technology with the potential for market penetration requires the capability of moving technology quickly through design and production to gain an advantage in the international market.

In general, the defense-oriented research programs assessed here have been valuable in solving specific problems related to U.S. Navy ships and in helping U.S. shipbuilding companies improve quality or reduce costs. But, like the results of other defense-oriented U.S. government programs, the fruits of Navy-sponsored research over the past decade have, in general, not transferred easily to the commercial world. Thus, funding for these programs, as they are currently structured, is not much of a contribution to the competitiveness of U.S. shipbuilders trying to enter commercial markets.

ONR efforts to observe and report on shipbuilding technology in Europe and Asia are important and relevant, however, especially when they are directed towards business practices.

SHIPBUILDING STANDARDS

The role of standards in the competitive success of a capital goods industry is not well understood in the United States. Some recent studies, most noticeably a 1994 study by the Office of Technology Assessment (Garcia, 1992), pointed out that standards are a method by which a market is maintained; therefore, the country that sets the standard is likely to have a greater impact on the market than countries that follow the standard. Although not formally structured, joint efforts are made through the ASTM, SNAME, and the NSRP to develop a complete and usable set of shipbuilding standards. This is an industry-led, government-supported program. It is difficult to put a dollar value on this program because most of the work is done on a "volunteer" basis. However, the salary and travel costs of the volunteers, from both industry and government, are mostly paid by their employers. Standards are important, although they will provide no competitive advantage against foreign yards, which—because of their market success—are in the position of setting international standards. However, it is important that U.S. shipbuilders become familiar with and capable of producing ships to international standards, especially ISO standards.

For this reason, it is important that the United States is represented by the current chair of the ISO Technical Committee on Ships and Marine Technology (ISO TC-8) and by the chairs of three subcommittees, Life Saving and Fire Protection, Marine Environment Protection, and Piping and Machinery. This connection provides information to U.S. shipbuilders on changes in international standards and ensures that U.S. practices are considered in developing standards.

An example of the detrimental effect of the lack of leadership in standards came in the 1960s when international standards were set for containers. In spite of the fact that 95 percent of the world's containers at that time were owned by two U.S. companies, international standards on size excluded existing containers.

NATIONAL MARITIME RESOURCE AND EDUCATION CENTER

MARAD recently established the National Maritime Resource and Education Center as an information source and facilitator for the maritime industry. The center is intended to help U.S. shipbuilding and allied industries improve international competitiveness and will provide relevant expertise, information, and reference material on commercial shipbuilding. Short-term goals will be establishing a Marine Industry Standards Library, assisting companies that wish to be qualified to ISO 9000 for quality assurance, conducting seminars and training, communicating with the U.S. Coast Guard to implement consensus standards in lieu of regulations, providing support to ISO TC-8, coordinating with ARPA on the MARITECH program, updating MARAD Guideline Specifications to include international standards and reflect metric dimensions, developing a three-dimensional computer-aided design library, and providing information on marine environmental protection. These short-term goals represent an ongoing effort to acquire and maintain marine standards; develop and conduct seminars and workshops on such topics as standards, regulations, and environmental concerns; and provide other information to industry. The center also addresses issues of business-processes and systems technologies—the areas that appear to be most critical to enhancing the competitiveness of U.S. commercial shipbuilding.

SUMMARY

An overview of existing programs is shown in Figure 3-1, which identifies the number of programs that address each technology area, and in Figure 3-2, which identifies the amount of money spent to develop each technology area. Although the programs appear to address all four areas of technology identified by the committee, the money invested heavily favors product technology for naval ships, with little investment by the government in business-process technology.

The greatest emphasis on business processes is in the MARITECH and BMP programs. The NSRP and the Navy Manufacturing Technology programs emphasize shipyard production processes; and the ONR Surface Ship Technology program, the Mid-Term Sealift Ship Technology Development program, and the Navy's Affordability Through Commonality program emphasize product technologies, although the last two are intended to improve shipyard production processes.

The lack of emphasis on business-process technology in these government programs may be appropriate from the standpoint of their intended purpose. Only the MARITECH and TRP programs, the National Maritime Resource and Education Center, and, to a certain extent, the NSRP, are intended to enhance international competitiveness in commercial shipbuilding. The principal purpose of the other programs is to improve the effectiveness of U.S. Navy ships through reduced cost and improved performance.

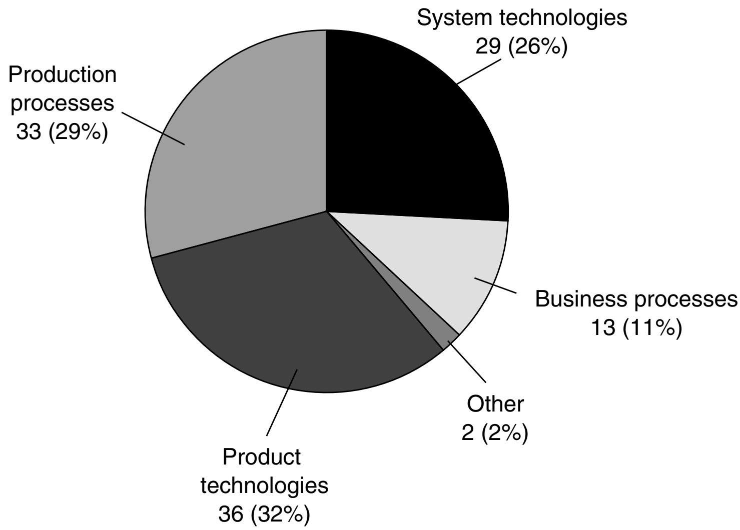

FIGURE 3-1 Number of programs addressing technology areas.

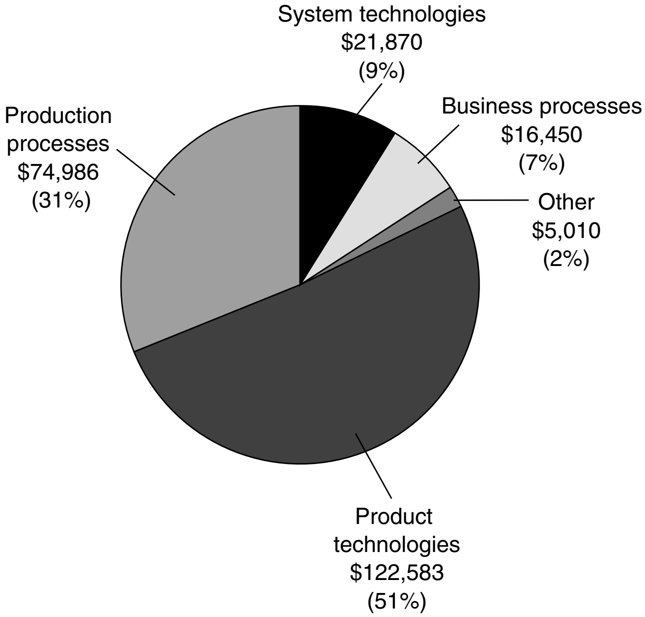

FIGURE 3-2 Dollar amounts (in thousands) invested in each technology area.

The emphasis on product technology for naval ships is in keeping with the goals of most existing programs, many of which are U.S. Navy programs intended to increase the fighting ability of ships. Programs that are directed solely at military capability are not included in Figures 3-1 and 3-2, but those that could benefit both military and commercial ships, such as projects on double-hull structure and improved propulsion, are included.

The relative levels of support for business and other technology areas are difficult to characterize easily. Although business-process technologies are the most critical for the future competitiveness of U.S. firms, improvement in this area must come mostly from companies investing their own funds and energies, as was made clear in Chapter 2. Similarly, although government investment in production processes is significant, shipbuilders will need to invest many times that amount to implement newly developed production technologies. In short, government can provide leadership in technology development, but industry must play a much greater role in carrying developments through. The committee was encouraged by discussions with the leaders of several shipyards that such investments are now being made. Continued investment will be necessary, however, because the U.S. shipbuilding industry has a long way to go.

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4

National Needs for Education Infrastructure in Maritime Technology

INTRODUCTION

This chapter assesses the state of education in naval architecture and marine engineering in the United States and identifies steps that should be taken to strengthen the education base to fulfill national shipbuilding goals. This chapter considers the need for education to produce both military and commercial ships.

Education is a broad term. In the context of the maritime industries, it includes education or training of the following:

- shipyard craftsmen and supervisors,
- ship operating personnel,
- designers of marine systems, and
- producers of new technology.

Although this chapter does not address the education of shipyard craftsmen and supervisors or ship operating personnel, this does not imply that education in these areas is unimportant to the commercial success of U.S. maritime industries.

SNAME reported to the committee that it considers 18 schools to have undergraduate programs in naval architecture and marine engineering.[1] The list includes two military academies, six maritime academies, nine departments within the schools of engineering of various universities, and one independent school. The military academies graduate as many people with degrees in naval

[1]Femenia, Jose, Jr. Presentation to the Committee on National Needs in Maritime Technology, National Research Council. May 24, 1994.

TABLE 4-1 Schools of Naval Architecture and Marine Engineering

University of California at Berkeley	The State University of New York Maritime College
California Maritime Academy	Texas A&M University at College Station
Florida Atlantic University	Texas A&M University at Galveston
Florida Institute of Technology	United States Coast Guard Academy
Great Lakes Maritime Academy	United States Merchant Marine Academy
Maine Maritime Academy	United States Naval Academy
Massachusetts Institute of Technology	Virginia Polytechnic Institute and State University
Massachusetts Maritime Academy	Webb Institute
The University of Michigan	
The University of New Orleans	

architecture as all of the other schools combined.[2] However, because they are structured for the primary purpose of developing U.S. Navy and U.S. Coast Guard officers, and the continued existence of these schools is, therefore, independent of the health of the commercial shipbuilding industry, they are not evaluated in this report. Similarly, because the maritime academies have in the past been structured for the primary purpose of developing officers for the merchant marine, these academies are not evaluated. Descriptions of the schools assessed by the committee are provided in Appendix E.

The committee selected a sample of the schools shown in Table 4-1 and focused attention on them.[3] These schools are the University of California at Berkeley (Berkeley), Massachusetts Institute of Technology (MIT), the University of Michigan (Michigan), the University of New Orleans (UNO), Virginia Polytechnic Institute and State University (Virginia Tech), and Webb Institute of Naval Architecture (Webb). The committee recognizes that a broader view of education in marine fields is necessary and urges further studies, particularly of the role of maritime academies in a period of decline for the U.S. Navy as well as the U.S.-flag merchant fleet.

Naval architecture is a traditional term for the hydrodynamic and structural design of ship hulls. Marine engineering encompasses the design of power systems and auxiliary equipment for ships. In U.S. universities, naval architecture and marine engineering are usually combined and considered as one program. In the United States, ocean engineering has grown from at least three distinct origins:

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[2]The importance of the academies to education in naval architecture is reflected by the fact that in 1993 the U.S. Naval Academy and the U.S. Coast Guard Academy together awarded more than 90 bachelor's degrees in naval architecture; the schools that the committee assessed awarded only 60 undergraduate degrees.

[3]The committee convened a "Workshop on Education in Naval Architecture" on October 18–19, 1994, in Washington, D.C. The workshop was attended by representatives of six of the schools considered by the committee. In addition, SNAME was represented, as was the Board on Engineering Education of the NRC. The schools represented at that workshop are those on which the committee focused its attention.

naval architecture, coastal (civil) engineering, and oceanography. The education needs of the offshore oil and gas industry have stimulated development of special-purpose programs that draw on both naval architecture and coastal engineering. In this report, except where otherwise stated, the committee considers naval architecture, marine engineering, and ocean engineering as a single field (NA&ME) concerned with the design of ships and floating or fixed ocean structures, including the hull and all machinery essential to their operation.

The committee has characterized the field as the design of complex engineering systems for the ocean environment. The nearest engineering relative is aeronautical and aerospace engineering, which also addresses the design of highly complex systems that operate in hostile environments. The terms naval architect, ocean engineer, and naval architect/marine engineer will generally be used interchangeably in this report. All refer to an engineer whose work is focused on both complex systems and the ocean environment. A special kind of education is required for this field, and it is provided by the institutions listed in Table 4-1.

The following sections address three questions about education in NA&ME:

Question 1. Will a revitalized U.S. maritime industry require the availability of specialized university-level education in NA&ME?

Question 2. How should educational institutions go about ensuring the existence of viable programs in this area?

Question 3. What measures should be taken by federal agencies to help ensure the existence of an adequate educational infrastructure to support U.S. maritime industries?

The fields of study and academic degrees awarded by the schools represented at the workshop are indicated in Table 4-2. The following discussion addresses the questions listed above.

NEED FOR SPECIALIZED PROGRAMS

Question 1: Will a revitalized U.S. maritime industry require the availability of specialized university-level education in NA&ME?

Academia will play a minor role in the short-term revitalization of the U.S. maritime industry; however, it will play an essential role in maintaining that industry. Here, "short term" implies about five years. One cannot expect education to have real impacts on this time scale. Changes to curricula require time to develop the faculty to teach new courses. Students must elect the program, become educated, and then work for several years in the industry before they have an effect. University research might have some—but not a major—impact in the short term. Thus the following discussion focuses on the long-term role of universities in maintaining a vigorous U.S. maritime industry.

TABLE 4-2 Fields of Study, Enrollment, and Degrees Awarded, by School

	1994 Undergraduate Enrollment				1994 Graduate Enrollment				
Institution	NA&ME	NA	OE	TOTAL	NA&ME	NA	OE	TOTAL	Degree Levels[a]
Berkeley		18		18		20	10	30	M,D[b]
MIT	1		9	10		52	54	106	B[c],M,E,D
Michigan	80			80	72[d]			72	B,M,E,D
UNO	90			90	12			12	B,M
Virginia Tech			50	50			10	10	B,M
Webb	75			75					B[e]

[a]The particular name of a degree varies among institutions, but the general educational level is:
B–Bachelor
M–Master
E–Engineer
D–Doctorate

[b]Two doctorates are offered by Berkeley—Ph.D. and Dr.Eng.; the bachelor's degree is no longer offered. Naval architecture at the B.S. level will be available only as an option in mechanical engineering.

[c]The bachelor's degree is offered by MIT only in Ocean Engineering.

[d]Graduate programs at Michigan are now being restructured in two tracks—marine hydrodynamics and marine environmental engineering and concurrent marine design.

[e]A new master's program is being planned by Webb in ocean technology and commerce.

In the long term, if the U.S. shipbuilding industry survives, either by becoming internationally competitive or by a resurgence of either U.S.-Navy or U.S.-flag vessels, an educational base will be needed to maintain technological capability. That is particularly true for an internationally competitive industry. Technological competence is a necessary condition for a viable industry. The schools of NA&ME have a definite role to play in educating future shipbuilders. However, some changes in the educational programs are necessary.

Kind of Specialized Education Required

What differentiates specialized university education in naval architecture and marine engineering from education in other fields of engineering? In what ways is it specialized? Twenty-five years ago the answer would have been confined to its single professional product, ships. During the 1970s, designers of platforms for offshore oil and gas exploration and production, who were primarily civil and petroleum engineers, discovered that naval architects were eminently prepared by the breadth of their education to design these platforms even though they had not studied this specific application. NA&ME education was evidently not limited to ship design. Furthermore, naval architects had always been concerned with the design of whole ships, developing design tools on hydrodynamics, structures, dynamics, metallurgy, thermodynamics, electric power, controls, and the like, as required by the task at hand. They were also concerned with the uses of the product, which required them to understand shipping systems; operation, finance, government regulation; and other nontechnological subjects. Clearly the field is broad in terms of both discipline and product.

Naval architecture and marine engineering education shares with the rest of engineering education the criticism that curricula must pay more attention to the development of communication and social skills; social and economic studies need to be integrated into the curricula. NA&ME curricula, like other engineering curricula, need to give consideration to business and management courses and capstone design projects. All six schools on which the committee focused attention include a capstone design course involving teaming. Numerous experiments to reform undergraduate engineering education are under way nationwide at the present time and are in various stages of development. It remains to be seen if an overall balance will be achieved between recognition of the need for reform and the necessity of imparting a necessary and sound basis of technical knowledge.

Much of the detailed engineering effort required in the design and construction of complex marine systems can be done effectively by persons educated in the more conventional areas of engineering, especially mechanical engineering. Overall system design requires input from professionals, like naval architects, who are educated to address issues involving entire marine systems. All major ship design and shipbuilding firms find it necessary to recruit and employ system synthesizers. These system synthesizers play a vital and necessary role in the ship design process.

Even in the current depressed state of U.S. shipbuilding, graduates of schools of NA&ME can find employment in the field. For example, Michigan reports that in spring 1994 22 B.S. graduates in NA&ME received 65 job offers in this field. Similarly, UNO is supported in NA&ME by the marine industry in the Gulf Coast region, and graduates who are not already employed by local industry readily find positions. In 1994, the 10 UNO NA&ME graduates with the degree of B.S. recorded more than 25 job offers in the field. The continued need for these schools is indicated by the employment of their graduates, notwithstanding the perception of entering students that job opportunities are poor.

Changes Needed in NA&ME Education

The idea that specialized NA&ME education will be critical in supporting a flourishing marine industry does not imply that no changes in NA&ME education are needed. In particular, NA&ME education has suffered from a basic shortcoming that reflects a major deficiency of the U.S. shipbuilding industry: students have been taught how to design complex ocean systems, but few have been taught how those systems are (or might be) fabricated; and there has not been much emphasis on designing for producibility. Although this shortcoming has not been limited to the maritime industry, it has been especially significant there, where engineering design and manufacturing have been carried out not only by separate groups of people with distinct cultures, but even in separate companies. Educational institutions did not create this situation, but until recently they did little or nothing to correct it. Fortunately, this is now changing. Michigan took the lead 15 years ago by addressing this need at the undergraduate level and now is reorganizing graduate studies as well to emphasize concurrent engineering. MIT's Naval Construction and Engineering Program has developed a significant component on shipbuilding methods and organization. The task is certainly not completed, but the problem has been identified, and substantial steps are being taken in the proper direction.

Another change needed in NA&ME education will be further discussed in connection with federal support for programs (Question 3). Education in the field is strongly affected by the interests and expertise of the faculty. Engineering professors in major academic institutions must be able to perform leading-edge research and obtain funding for it. This is a fact of academic life and an integral part of higher education in engineering in the United States. Pressures on young faculty members cause them to direct their scholarly attention toward available research funding or face serious limitations on their careers. Eventually, these forces can distort the balance of the educational experience.

Ship fabrication is an important and timely example. Research on producibility has been funded by industry and government largely through the NSRP, which focuses on direct applications but not the theoretical aspects needed to further the careers of junior faculty members. Another example is found in the shortage of faculty to teach marine structural design. This is a critical field because of high industry demands for marine structural engineers to design offshore exploration and production platforms. University research funding that has been available in this area is largely through the interagency Ship Structure Committee (SSC), which does not emphasize academic aspects of research. As a result, few faculty members focus on ship structures, and few students pursue doctorates in this area. At present, there is virtually no pool of new faculty talent to provide educational or technological leadership in these areas.

There is often a gulf in major research universities between the faculty and students who are oriented more towards design and practical applications and those who are more oriented towards research. Some schools have recognized this gulf and are evolving programs toward innovation and change, a process that would profit from greater industrial involvement.

There is also a diversity of educational institutions, with some emphasizing design, synthesis and the application of engineering science to engineering practice, others emphasizing cutting edge research. A strength of the U.S. educational system is that students are offered choices among institutions and educational programs.

Number of Professional Graduates Required

Most of the engineers who participate in the design of complex ocean systems do not need to be educated specifically for that purpose. Many subtasks can be performed by individuals educated in other engineering disciplines. But it is critical that some engineers be educated in the design of complex systems and that they understand the unique constraints imposed by the marine environment so that there will be some leaders in marine system design. These unique requirements are recognized by several state boards for registration of professional engineers that provide separate licenses for NA&ME. How many NA&ME graduates are needed? Realistic estimates would require accurate predictions of the size of the industry some years in the future. Such numbers are not available, and the current level of employment provides no insight for this purpose.

Since future marine-industry needs for specially educated engineers are not known, the committee chose to ask instead what the minimum level of education in this field must be to survive. Based upon the number of current faculty members, the nation now has some over-capacity for producing new graduates at the bachelor's and master's levels. This is because all of the institutions listed, except Webb, could quickly increase throughput to meet any foreseeable short-term demand for graduates (provided, of course, that they can recruit more students). But the number of programs is so small that the diversity of programs will be lost if that number is significantly reduced. Some differences among the programs will be described later in connection with Question 3. Current programs operate on different philosophies, attract students from varied sources, produce graduates with somewhat differing identifiable capabilities, and support themselves in different ways. The committee considers this diversity just as important as the capacity to produce a prescribed number of graduates. The capability of growing in the future, should a resurgence of either commercial or naval shipbuilding occur, also requires that these programs continue to exist.

PROGRAM VIABILITY

Question 2: How should educational institutions go about ensuring the existence of viable programs in this area?

There is no single prescription for all six institutions listed above. With the exception of Webb Institute, the educational programs relevant to this study reside within larger institutions. Among these, there is tremendous diversity in size, scope, organization, and culture. We can set down some general conditions for viability of the educational enterprise in this field, but they do not apply equally to all of the institutions listed. Nevertheless, program viability requires generally that:

- the program address real-world engineering needs;
- employment and career opportunities exist for graduates;
- students be attracted to the program;
- means be available to pay the costs of offering the program; and
- institutional expectations of the program be satisfied.

The paragraphs that follow discuss the five conditions listed above. For the most part, this discussion is limited to bachelor's and master's degree programs, which are the primary source of professional engineers for the field.

Addressing Real-World Engineering Needs

The need to teach ship production and producibility was mentioned above. This change in curriculum should be part of a larger effort to address more than traditional academic needs. In order to be viable in the current economic and political climate, engineering academic institutions must identify and address the real-world needs of the professions they serve. Because they vary widely, institutions inevitably define real-world needs in different ways and respond to them differently. As an example, consider the historic, ongoing dialogue between academia and industry as to whether engineering graduates should, or can, be produced who are ready to perform useful engineering work from day one or whether employers should plan on providing a period of intensive training for new graduates who are well versed in basic principles. There is no single answer to this question. Either approach can be claimed to address real-world needs. In fact, the nation needs both.

One of the most important real-world needs that should be addressed is the health of the U.S. shipbuilding industry. Outside the NA&ME faculties, there is extensive knowledge in process simulation. As was shown in Chapter 2, this knowledge is essential if U.S. yards are to restructure themselves at minimum capital cost in order to approach world-class yard economics. Individual faculty members can also become deeply involved with the members of the industry in trying to become competitive through purely technical improvements and through a mix of technical and economic improvements in process engineering, tooling, material processing, and the like.

In many countries, including some of the leading ship-producing countries, higher education is centrally controlled, and dual levels of engineering education were established precisely for the purpose of providing the two kinds of engineering graduates described above. The two tracks are rigidly defined and are distinguished by different diplomas or degrees. In the U.S., each institution constructs its own engineering curriculum within the framework of minimum accreditation criteria, and each awards the bachelor's degree. This diversity among educational institutions is a great strength of the U.S. education system. It allows schools flexibility to adapt to changing environments. But there must be enough viable institutions in the field to allow for experimentation. The alternative is for a higher authority to define multiple tracks and ensure that at least one institution survives in each track.

Employment and Career Opportunities

Many young people study history, literature, philosophy, and so on, because they perceive that such studies give them a well-rounded education. Engineering education is by its nature professional education. If the profession and related industries are not vigorous, the supporting academic programs will wither away. On the other hand, if the U.S. shipbuilding industry does indeed succeed in competing internationally, thus revitalizing itself, it will need many more naval architects and ocean engineers than are entering the profession at present. There are more than five years between the time an undergraduate engineering student elects a program of study and the time that individual becomes sufficiently competent to work in the field. Therefore, students should be recruited now if commercial shipbuilding becomes a viable industry in five years.

However, because engineering students select fields of study based on their perceptions of the future job market, schools may have to broaden the range of engineering activities to assure students that good jobs will indeed be available. In effect, the marine field accomplished this in the 1970s when the offshore oil and gas industry recognized the relevance of NA&ME education. This broadening of activities could be repeated today by addressing marine environmental issues. Potential careers may not be the ones traditionally identified in the marine field, but the education needed for such careers will be similar to the education for NA&ME.

Among the schools of NA&ME assessed by the committee, most have already taken some steps to diversify in ways that expand professional opportunities for their students. In this respect, UNO may be an exception, for the simple reason that its geographical location and intimate involvement with successful local industry make diversification unnecessary and, perhaps, undesirable. If the marine industry succeeds in building itself up once again nationally, other educational institutions may be able to follow UNO's example in this respect. In general, educational institutions must be able to identify future employment and career opportunities for their engineering graduates if their programs are to remain viable. In addition, employment in the marine industry can begin with work-study programs, such as the eight-week winter work term at Webb, or through other co-op programs where the student spends one semester in school and the next on the job. Such programs require substantial commitments from industrial sponsors, but the results can be substantial. Benefits to the school are increased enrollment, to the student a realistic perspective on industry needs, and to the industry sponsor greater educational focus on industry needs.

Attracting Students

Engineering academic staff members are continually impressed by the sensitivity of students to perceived fluctuations in job markets. When the aerospace industry went into decline after the shutdown of the U.S. moon-exploration program in the early 1970s, aeronautical and aerospace programs across the country experienced catastrophic drops in enrollment; decreases of 75 percent were common. There was a similar phenomenon in chemical engineering in the early 1980s, when enrollments dropped by as much as 50 percent in just two years—also in response to changing job markets. It is hardly surprising then that most NA&ME and ocean-engineering programs have difficulty attracting students at this time. Only at UNO are students likely to opt for NA&ME because they know that good jobs are available locally. In fact, many full-time NA&ME students at UNO have obtained part-time employment in New Orleans naval architecture firms and local shipyards, and only five of UNO's 90 NA&ME students are part-time.

But students have also been attracted to NA&ME for other reasons. In annual polls taken by the Michigan NA&ME Department over a number of years, more than 80 percent of the students said they wanted to design sailing yachts. Many students were willing to sublimate that desire to designing commercial or military vessels or even offshore platforms.

Other countries constitute another source of NA&ME students. For decades, outstanding young people from other countries have been attracted to U.S. universities, especially to graduate programs. Many have subsequently moved into U.S. industry and government.

In large academic institutions, low undergraduate enrollment is viewed as a sign of weakness in the field, the program, or both, and a department is viewed critically if the number of student credit hours taught per faculty member is unusually low. Student/faculty ratios strongly influence the status of a program, including faculty positions, office and laboratory space, equipment, support services, and the like. The full negative impact of low undergraduate enrollment may be mitigated by large graduate student enrollment and high research volume, but a department with low undergraduate enrollment can expect trouble. Thus, attracting more students is a high priority of all university-based NA&ME and ocean engineering undergraduate programs. Institutions need to find ways to convey to potential students that career opportunities are not limited by the current state of the U.S. shipbuilding industry. That message should be addressed to students in high school, or even younger, preferably by involving active professional engineers.

Reducing Costs

Most universities in the United States are now facing severe financial constraints; containing costs and expanding revenues have become major objectives. All of the educational institutions serving the maritime sector, including those with high tuition, provide education at a loss. This loss must be covered by a combination of income from endowment, gifts, and (in public universities) state funds. In this climate, universities cannot be expected to recognize any intrinsic obligation to support U.S. maritime industries or the U.S. Navy. Among the six institutions considered by the committee, only Webb and UNO have deep commitments to this field.

As they try to reduce costs, institutions may decide to offer fewer but larger classes, taking advantage of an economy of scale. If undergraduate enrollments are very low, however, as they are in NA&ME and ocean engineering programs, this option is not available. In this case, administrative attention is likely to turn to the larger savings that can be realized by eliminating small programs and saving the cost of faculty salaries.

Merging small departments into larger ones is another mechanism for achieving modest savings, and the administrations of MIT, Michigan, and Berkeley have considered this option for the departments of concern here. The intent would be that the programs would continue to exist, although the departments would vanish. Such mergers appear to be on hold at these institutions for the moment.

Reducing costs and increasing revenues will be continuing concerns for all universities and will be especially pertinent to the future of small programs, such as the ones considered here. Except at Webb, the consequences could be alleviated by the increased enrollment that would accompany a renaissance in the marine industry or a major diversification of the field. A similar result might be achieved in all institutions, including Webb, if alternate sources, such as gifts to endow professorships, could be found.

Research funds do not reduce the basic cost of engineering education. They can pay the tuition costs of graduate students who participate in the research, broaden the institution's indirect-cost base, and pay a fraction of the salary of faculty grantees. But the financial benefits of research funding, while important, are minor compared to the cost of the educational programs themselves.

FEDERAL SUPPORT FOR PROGRAMS

Question 3: What measures should be taken by federal agencies to help ensure the existence of an adequate educational infrastructure to support U.S. maritime industries?

Background

Much of the educational infrastructure in this field would not exist if it were not for actions by federal agencies in the past. In particular, naval architecture programs at Michigan, MIT, and Berkeley can all be traced directly to U.S. Navy initiatives, which took completely different forms in the three cases. It is worth noting how this happened before we look ahead for new models of cooperation.

In the late 1870s, Congress authorized the U.S. Navy to assign officers to a number of universities as "professors of iron shipbuilding and steam engineering." These fields were at the forefront of technology of the day. In the field of steam engineering, the Navy was the national leader in developing new technology. U.S. universities were ill-prepared to teach these subjects—a condition the new program was intended to correct. About a dozen young officers were sent to as many institutions, and a plethora of teaching programs came into being. Most of these programs vanished in the following decades, but the one at Michigan survived because the young lieutenant sent there in 1881 was a remarkable leader who dedicated his life to the university.

The creation of the MIT NA&ME Department in 1893 did not result from specific U.S. Navy action, but a strong Navy presence was soon established. Since 1901, MIT has maintained a graduate program primarily for engineering duty officers who go on to manage the design of U.S. Navy ships. For much of that time, the Navy has also assigned active-duty engineering officers to MIT's teaching staff. There has never been a contract between MIT and the Navy relating to this program. U.S. Navy students are admitted, and Navy faculty members are appointed, through normal MIT procedures. There have been times when the Navy program dominated the department and other times when it did not.[4] Over the years, the program has been a model of voluntary collaboration for the mutual benefit of MIT and the Navy. Currently, most of the graduate students in the ship design option at MIT are U.S. Navy officers.

In the mid-1950s, ONR determined that the nation needed a new program of graduate study and research relating to ships. A generous and flexible research contract was awarded to the University of California at Berkeley to help make this happen. At the same time, ONR encouraged U.S. Navy agencies to send civilians and officers to Berkeley to earn master's or doctor's degrees. The result was a generation of young people educated in a research tradition different from that of either MIT or Michigan. The Berkeley program continued with little change in concept until the late 1970s, when an undergraduate degree program was added and diversification into offshore engineering was incorporated. (The B.S. program is no longer offered as a separate degree at Berkeley.)

It is unlikely that any of these institutions would have started and maintained such programs but for the intercession of the federal government. These are all institutions that had previously been described as having no "intrinsic obligation to support U.S. maritime industries or the U.S. Navy," but they all recognized the opportunity of serving the nation and providing leadership in education and research. They picked up on U.S. Navy initiatives and extended them. Eventually, each of the schools devoted substantial resources of its own to meeting these national needs.

A clear indication of the educational need as perceived by industry is the

[4]At present, less than one-fourth of the students in the NA&ME Department are military personnel.

establishment of the NA&ME academic program at the UNO, which is part of the Louisiana State University system. In the late 1970s, the expansion in offshore oil-field development resulted in a shortage of naval architects and marine engineers. This shortage of trained engineers limited commercial opportunities and led a group of industry leaders in the New Orleans area to develop the intellectual and political case for the creation of an NA&ME program in the Louisiana State University system. Their case proved to be so strong that the State of Louisiana appropriated funds for new facilities for the entire UNO College of Engineering to ensure that the new NA&ME program had well-equipped laboratories in a modern engineering environment. Today, the UNO NA&ME program is well established and respected, fulfilling the vision of industry leaders in that area 15 years ago.

Webb, Virginia Tech, and UNO all established their NA&ME/Ocean Engineering education programs without direct federal involvement. This demonstrates that education in this field is not necessarily dependent on the federal government. However, it is noteworthy that three-quarters of a century elapsed between the founding of Webb Institute and the establishment of the next program not initiated by the Navy, the ocean engineering program at Virginia Tech; UNO came still later.

Although the federal government is not the only organization providing support for education in NA&ME, it has played a crucial role. Some academic programs have managed to survive and sometimes even thrive because of research support from federal agencies. Such support at universities does little to reduce the cost of professional education, but it does benefit marine education by enhancing the image of the recipient department in the eyes of the university administration. This increases the likelihood that the department will receive institutional resources to support partially faculty researchers, pay for laboratory development, and support the development of the next generation of professors.

ONR has been, by far, the most consistent source of research funds in this field in the post-World War II era. However, significant support has also been received from U.S. Navy laboratories, MARAD, the U.S. Coast Guard, the National Science Foundation, and the Sea Grant Program of the National Oceanic and Atmospheric Administration (NOAA). There has been no sustained federal interest in the education of engineers to design and build ships, although, occasionally, there is an especially articulate advocate for education within an agency. This occurred in ONR in the 1950s and led to the creation of the program at Berkeley. In the mid-1970s, NA&ME education found a temporary champion in the National Science Foundation (NSF) Education Directorate. But these episodes were short-lived, and they did not reflect sustained concern for the promotion of education.

Mechanisms for Support of Education

Support of education in NA&ME is an important and ongoing concern of several government agencies, but it is not the dominant concern of any. Mechanisms are needed for strengthening that support, possibly by bringing agencies together to combine available resources for the support and development of education. Four alternative support mechanisms are:

- individual federal agency efforts;
- coordination among agencies and with academia;
- public-private partnerships; and
- academic-led consortia.

Individual Federal Agency Efforts

If a coordinating group were established for support of education in NA&ME, it would operate best if it had nongovernmental members, including academic institutions and industry. In the current atmosphere of federal austerity, it is not expected that federal agencies will devote major new resources to maritime education infrastructure. However, ONR-funded research currently supports graduate students, some of whom are future professors. ONR has also awarded graduate-study fellowships that are not directly linked to research programs. Indeed, ONR has an explicit mandate to promote the development of manpower in its mission areas, but there appears to be little discussion between ONR and other interested groups on how these programs might better serve long-term purposes. Two examples illustrate the importance of early and broad consultation.

Ship production was not systematically taught in any of our universities until very recently. At the same time, MARAD (in the 1970s) and the U.S. Navy (in the 1980s) funded the NSRP. However, because of the way the NSRP is structured not all universities can participate. Development of research programs that meet the combined needs of the academic institutions, industry, and government will promote the growth of programs in this area.

The present critical nationwide shortage of professors of ship structures may be largely attributable to the fact that the U.S. Navy, MARAD, and the U.S. Coast Guard have not meaningfully addressed professional development in this area. They have sponsored research in ship structures, but not enough to develop the needed faculty or to encourage graduate students to elect studies in this area. Additional basic research at the universities is needed.

Certain areas have been neglected in our academic institutions because of insufficient research opportunities for faculty and graduate students. As a result, the pool of potential faculty talent is inadequate. In naval architecture and ocean engineering, this has been the case for at least two decades in structural mechanics. It was also the case in manufacturing technologies. These fields do not have priority in terms of the technological needs of the U.S. Navy to justify expenditure on a large scale. Because of a lack of funding, faculty development is not encouraged in these areas.

In the fall of 1994 the ONR established the Gulf Coast Marine Technology Center at UNO and at Lamar University in Orange, Texas. The goal of the center is to make the U.S. shipbuilding industry more competitive on an international scale.

MARAD designated the National Maritime Enhancement Institute (NMEI) program in 1990, under which all academic institutions were eligible to compete for NMEI designation. Four institutions were selected: Berkeley, MIT, Memphis State University, and Louisiana State University. Each was selected for a "program area" or an area of specialty for which they demonstrated "world class" competence. Although very little funding has been made available for the implementation of this program, and although its future is in doubt, the program represents another possible base on which to build a broader program of support for research that can enhance the educational base.

Coordination among Agencies and with Academia

Several federal agencies have an interest in supporting education in NA&ME, but no agency has the resources or the charter to do this alone. A unified effort among several agencies may make a significant difference.

A possible organizational model for coordination among agencies is the SSC, an organization of several government agencies that promotes safety, economy, marine environmental protection, and education in the North American maritime industry. Although the SSC is effective in supporting research in ship structures, the research projects do not coincide with the needs of some educational institutions to develop and maintain faculty members who specialize in ship structures. The SSC is currently assessing education in ship structural design and construction to determine how to correct these problems. This effort could be expanded with a combined effort to cover education in the entire field on NA&ME.

Public Private Consortia

There are several industry consortia today that support research at schools of NA&ME. Examples are discussed below.

Joint MIT-Industry Project on Tanker Safety

This project began at MIT in 1992 with the support of about 20 different sponsors representing shipyards, ship classification societies, shipowners, and government agencies. The consortium has an annual budget of about $500,000 for investigating methods of predicting damage to oil tankers that run aground. To date, 26 graduate students have worked on the tanker-safety project and prepared theses and dissertations based on that work. Ten graduate students were financially supported by the project.

Structural Maintenance for New and Existing Ships

This project began at Berkeley in 1990 with the support of about 15 different sponsors representing oil-tanker owners, shipbuilders, ship classification societies, and government agencies. The consortium had an annual budget of about $450,000 to study the structural maintenance of oil tankers. This project was completed in 1993 but has been replaced by a series of smaller projects. There are usually four or five projects every year, with four sponsors for each who contribute $15,000 apiece.

These consortia are models of how to provide industry support to universities. The money provided supports research facilities and graduate students throughout their dissertations. Most important, a link is established between industry and the university so that research is relevant to both academic and commercial interests.

The examples above highlight current efforts to support education in NA&ME. What they do not provide is a unified approach to the problem. A possible forum for a unified effort is the Education Committee of SNAME. The overall society membership comes from all aspects of NA&ME. Although the committee currently has members from both industry and academia, there is only one member from a government agency. The current interests of the committee are licensing naval architects and marine engineers, continuing education in NA&ME, and accreditation of university programs in NA&ME. To be effective as a public-private-academic partnership to strengthen the teaching of NA&ME, representation is needed from government agencies, and support of education must become a primary focus.

Other efforts to support education in NA&ME include Panel 9, Education and Training, of the NSRP. Although the emphasis of the panel is on shipyard training, there have been efforts to promote the teaching of ship production in universities (see Appendix D).

Recruitment of Students

It has already been noted that, as modest as the demand is for naval architects and ocean engineers, the supply is even poorer. The perception of bad times in the industry has outrun reality, and the pool of interested young people is inadequate to meet the current demands of industry and government. ONR has had difficulty finding outstanding college seniors interested in applying for existing fellowships. A fundamental approach to these problems would involve addressing students in high school or even earlier. Since that might require an effort beyond the scope of these agencies, an alternative might be a campaign to attract undergraduates from other fields of engineering. One model for doing this is the NSF Research Experiences for Undergraduates Program. Of course, ONR contracts and grants already support some undergraduates in research projects, but not in a coordinated program to attract students. For example, most or all of the NA&ME/Ocean Engineering institutions could offer summer research opportunities, even if they did not have relevant ongoing ONR projects. These summer positions would be attractive to undergraduates both financially and intellectually, and the cost would be moderate.

SUMMARY

Life at a university can be extremely competitive on both a personal level and a program or departmental level. There is no simple "bottom line" by which evaluations can be made, a fact that gives added importance to some subjective criteria. The health and even the survival of NA&ME programs may depend on their being able to demonstrate that intellectual diversity is critical. At the same time, programs must also demonstrate their worth according to the standards, both objective and subjective, applied to more conventional programs. Universities will need the active support of industry and government to accomplish this.

The institutions discussed in this report are expected to produce the naval architects and ocean engineers for future naval construction and a resurgent commercial shipbuilding industry. Their ability to do so, however, depends upon their continued existence. Many programs are in decline, and there is no unified effort to change the situation. If the number of programs in a field is too small, there will not be enough latitude or redundancy for experiments to be made in institutional programs. If the number of institutions decreases, the United States risks losing the capability to educate engineers specifically for the marine industries. If this capability is ever lost, it will be extremely difficult to recover it. This study would suggest that modest steps and investments can avoid such a national crisis as the loss of our NA&ME educational pipeline; absent such attention, a crisis looms. The committee recognizes that a broader view of education in marine fields is necessary and urges further study, particularly of the role of maritime academies in a period of decline of both the U.S. Navy and the U.S.-flag merchant fleet.

5

Conclusions and Recommendations

OVERVIEW

Improved technology is critical if U.S. shipbuilding companies are to regain a place in the world commercial shipbuilding market. To be profitable, it is necessary that U.S. shipbuilders at least be on a technical par with the international yards against which they would compete. However,U.S. shipbuilders currently lag behind in the four major categories of technology that this committee examined:

- business-process technologies—the principal "up front" management processes and other management activities, notably technologies for preliminary design, bidding, estimating, and sourcing, that are linked to the marketing capabilities of shipbuilders;
- system technologies—the engineering systems, such as process engineering and computer-aided design and manufacturing, that support shipyard operations;
- shipyard production processes technology—the methods used in fabricating, assembling, erecting, and outfitting vessels; and
- new materials and new product technologies—the innovations, including new designs and new components, that meet particular market needs;

Relative to these four categories of technology, as they are commercially applied, U.S. builders lag behind least in shipyard production technologies, are further behind in system technologies, and are far behind in business-process and new product and new materials technologies. This assessment of the committee is based on extensive experience and visits to international yards, knowledge of technical exchange agreements between U.S. and international yards, and the committee's workshop and literature review.

The committee must make the sober observation that no industry in a position similar to the position of U.S. shipbuilding has become internationally competitive in less than ten years, if at all. Given the current position of U.S. industry, with labor hours twice the international level in some market segments, the industry confronts an enormous task.

This committee urges a broader examination—focused on more than technology—to determine what is required for the success of the industry. In particular, this examination should cover financing of all kinds, with a close look at U.S. government regulations and subventions by other governments through training programs, port and area development subsidies, and the like, which are not directly tied to shipbuilding but clearly influence its economics. In the past, financing has been much more important than technology in determining the competitive position of shipbuilders, and this will probably be true in the future. The proposed broader examination could be led by the industry, with cooperation from the federal government. In taking this broad view, such an examination should ensure that total support for U.S. shipbuilding leads to a total change in the industry and not a continuation of past practices. This broader examination should also include the need for the United States to formulate a public policy approach that creates organizational, structural and financial incentives. The range of incentives may be essential for building a viable industry in the United States.

SPECIFIC CONCLUSIONS

The following summarizes the committee's conclusions for U.S. industry, government, and education to regain an international market position for U.S. shipbuilding.

Conclusion 1: U.S. industry is behind other shipbuilding nations in *all four categories of commercial technology*: business-process, system, shipyard production, and new products and new materials technologies. Although U.S. shipbuilders are the best warship builders in the world, they have had almost no experience in commercial shipbuilding for the last 15 years and no significant international commercial experience for the last 50 years.

Conclusion 2: U.S. shipbuilders are at a serious disadvantage in *business-process technologies*, including marketing, preliminary design, estimating, and sourcing. Having been absent from the commercial markets for large ships for many years, U.S. yards do not understand customers well, do not have libraries of product designs, and are unaccustomed to rapid, accurate parametric cost estimating based on recent commercial ship production. U.S. builders must acquire better technical capabilities corresponding to preliminary design, estimating, sourcing, costing, quality, delivery, and adapting designs to customer needs. They must also acquire a better understanding of the close relationships among these capabilities. For example, foreign shipbuilders have developed regular working relationships with suppliers and are able to procure good quality components rapidly and cost-effectively; whereas U.S. shipbuilders, constrained by U.S. government procurement regulations, have little experience with international equipment suppliers. Similarly, U.S. builders have little knowledge of commercial customers and market segments. In other industries, building this kind of knowledge has been time consuming and expensive.

Conclusion 3: *System technologies*, engineering and manufacturing systems that support the yard, are also behind international practice. Although U.S. shipbuilders understand quite well the CAD/CAM models currently used and often use the same models as international shipbuilders, the aggregate of foreign experience results in simpler and more accurate construction, faster planning and estimating of shipyard labor hours, and fewer engineering labor hours per ship. Moreover, most U.S. yards are constrained by physical location and U.S. environmental standards. Improving the basic layout and material flows to international standards will be difficult and will require a high degree of process simulation to minimize capital costs while improving process flow and unit cost. Such process simulation technology now has many other applications, but it must be adapted for commercial shipbuilding so that yards can reprocess their work flows within financial constraints.

Conclusion 4: Within the shipyards, U.S. shipbuilders are behind in the commercial aspects of *shipyard production processes technology*. Although the basic technology is well understood and the technology being applied in international yards has been observed and analyzed by U.S. shipbuilders, the labor hours required by foreign shipbuilders are as much as 50 percent fewer than those required by their U.S. counterparts. In addition, foreign builders cut and weld more complex shapes to closer tolerances and to international commercial standards. As in other industries, such as automobiles and machine tools, international competitors are producing high quality products faster and at lower cost than the United States.

Conclusion 5: U.S. shipbuilders, again because of their long absence from the international market, do not have close knowledge of customer requirements or ready *product designs and materials technologies* to serve different commercial market segments. For example, fast ferries are being made in Australia, other ferries in Europe, and cruise ships in both Scandinavia and Italy. The Koreans and Japanese are building tankers and other bulk carriers. U.S. shipyards will in some ways have to start from the beginning, competing against yards that have designs that are "almost ready" to build. In addition, U.S. experience with new technologies, particularly with components and engineered products that go into commercial vessels, is minimal. Although U.S. builders have superb systems and engineering skills, they have little practice at integrating components to satisfy customer requirements. Once again, obtaining this experience will take time and money.

Conclusion 6: *U.S. government programs* have been and are helpful for U.S. shipbuilders trying to reenter commercial shipbuilding. But they are not sufficient. Specifically, the ARPA MARITECH program at $40 million a year is similar in scale to the amount invested in technology by the international yards. MARITECH's budget and the associated matching funds from participating companies represents about 2 to 3 percent of U.S. sales if the U.S. production goal is to produce 30 to 50 large commercial ships per year. Thus, MARITECH can potentially match the technology investment of international competitors. During the early phases of MARITECH, the focus has also been on the "front end" of the shipbuilding process, that is, on new marketing and preproduction and on product design and materials, the areas where the industry is weakest. MARITECH, then, is of about sufficient scale and has been directed at the areas of greatest need. Continued support of these front-end areas, including process modeling, is a way government can help. Continued support for shipyard production and design technology improvements is desirable, but it will have a modest effect unless there is an innovation that will capture customers or substantially reduce cost. In short, the MARITECH program should be allowed to run its course.

However, MARITECH is structured so that project results are proprietary to participants, thus limiting the effectiveness of the program to the U.S. shipbuilding industry as a whole. Thus, shipbuilders are encouraged to participate, but the results of MARITECH programs that are useful to all U.S. shipbuilders should be made available to all of them.

The NSRP, concentrating on standards, technical evolution of components, and processing, is helpful and of good quality, although it is substantially subscale. Unless NSRP encourages shipbuilders to spend several times the amount NSRP provides, the program will not be robust enough to make a difference.

U.S. shipyards possess skills of a very high technical order and can produce vessels whose technical sophistication is far greater than is required for commercial fleets. But high technology comes at a high cost. The many other shipbuilding-related programs that the committee examined offer very high technology but at costs that are prohibitive for the international commercial market.

For many years the government programs that have been the most consequential have been financial, not technical, programs. The construction differential subsidy in the 1970s and Title XI, more recently, have clearly made a much greater difference than technical programs. The implications, however, are beyond the scope of this report.

To improve the U.S. position, perhaps the most important help government could now provide would be U.S. Navy procurement of noncombat ships made to commercial specifications. Although it may not be practical for all noncombat ships, Navy procurement represents the largest single shipbuilding budget and has the greatest potential for improving U.S. industry's commercial performance. It would be important that the material and equipment used for these ships be commercial items used in commercial ship construction, not items based on military specifications that had been converted to commercial specifications.

Conclusion 7: *The educational system*, which produces the naval architects and marine engineers with a basic understanding of design and materials and the systems thinking needed to design ships, is absolutely essential to the long-term health of the U.S. shipbuilding industry. In the long run, the development of systems thinking and analysis, together with basic technical research (often funded by ONR), will be important to the U.S. position in international shipbuilding. It is equally clear, however, that education, because its effects are seen over such a long time, cannot make a material difference in the next five to ten critical years as U.S. shipyards try to regain a position in international shipbuilding.

In the short run, university faculties could help in several ways. For example, outside the NA&ME faculties, there is extensive knowledge in process simulation, which is the only approach this committee believes will allow U.S. yards to restructure themselves at minimal capital cost to approximate world-class yard economics.

As the industry becomes more successful commercially, more undergraduates will likely be attracted to the industry. The evidence suggests that in any technological area, including NA&ME, students are likely to choose a technical field only if jobs exist after graduation. Until U.S. shipbuilders create a demand for more graduates, ONR can continue to provide an extremely valuable function by funding research for faculty members, funding Navy projects, and providing fellowships. In fact, this may be the only source of support for some young faculty members.

The committee was unable to determine whether there will be a shortage of NA&ME graduates in the next several years. First, many past NA&ME graduates have turned to other industries where there are jobs. A good number of these graduates could return to the field with three to five years of experience in industry and be satisfactory naval architects and marine engineers.

Deep involvement of NA&ME faculty members with the industry in trying to help it become competitive is not apparent. When other industries were seriously challenged by international competition, the faculty of related schools made efforts that were not purely technical but were also designed to bring about both technical and economic improvements in process engineering, tooling, material processing, and the like. NA&ME faculties contribute little to the economic health of the U.S. shipbuilding industry. In turn, the shipbuilding industry seems to contribute little to the health of the schools. The common distress of both should mark the beginning of a common effort to strengthen both.

Conclusion 8: Judged by the difficulty that other industries have encountered, the *magnitude of the task* of regaining a significant share of international shipbuilding is enormous. No other substantial industry has achieved such a turnaround. Industries that have been severely damaged by international competition and recovered were still in their markets and took several years to learn new skills to become serious international players. This is true for the electronics, electrical equipment, automobile, and steel industries, for example. All of them had to invest and incurred large losses over several years to reestablish a position. This fact argues against the likelihood of success for U.S. shipbuilders, at least from a banker's perspective. For shipbuilders, it simply calibrates the difficulty of their task and helps to establish the level and quality of effort that will be needed for success.

POLICY RECOMMENDATIONS

Recommendations for Industry

Recommendation 1. Individual shipbuilders should develop detailed plans for entry into the international commercial market. To ensure a high probability of success in becoming competitive, shipbuilders must develop comprehensive strategies and detailed plans. These plans must cover required building hours, quality levels, skills, and management systems in detail. This recommendation might seem trivial or not particularly helpful. But discussions with executives in industries that have regained international positions against tough competition invariably indicate that a better early understanding of the difficulties, the competitors, and the customers would have made a major difference.

Plans also need to include reasonably good estimates of capital expenditures and their timing, the risks of achieving success in different market segments, and of the likely levels of yard manpower, which almost certainly will be substantially lower than the manpower levels required for construction of military ships. Detailed plans may be more than a single yard can afford. Corporate owners of shipyards will almost certainly require reasonable expectations of return before investing the amounts that are likely to be needed. Although such recommendations may seem self-evident, they were not evident to automotive, steel, and electronics companies, except in hindsight.

Recommendation 2. Shipbuilders and shipowners should become more involved with and supportive of schools of NA&ME. During the current decline of the shipbuilding industry, looking at the health of education may be difficult, but doing so is essential to the long-term health of the shipbuilding industry.

Recommendations for Government

Recommendation 3. The Department of Defense should acquire all noncombatant ships, including Sealift ships, using commercial specifications and commercial procurement practices. Current procurement practices create inherently inefficient design, engineering and procurement practices in U.S. shipyards. The business methods developed to meet these procurement requirements are entrenched in U.S. yards and leave them unable to operate effectively in the international marketplace.

Recommendation 4. ARPA should continue current efforts in MARITECH, concentrating on the "front end" of the process. Until the industry reaches a level of investment approximating that of European yards for technology and capital, only ARPA is investing at the scale required for the industry to become competitive. The "front end" includes both business-process technologies, such as marketing, estimating, sourcing, and process simulation, and technologies related to product design. ARPA should insist on viable business plans for each project, and if they are lacking, should cancel the project and concentrate funds where there is a reasonable chance of success.

Recommendation 5. The Maritime Administration (MARAD) should continue and should expand its role in assisting U.S. yards to enter the international commercial market. MARAD should be more aggressive as an informed commentator on efforts required by the industry to become internationally competitive. MARAD can also help by collecting general market information, much like the departments of Commerce or Labor, but success will depend on individual shipbuilders understanding their target market segments to a depth well beyond that achievable by MARAD. Nevertheless, MARAD, by combining information from the departments of State, Commerce, Defense, Labor, and Transportation, can provide useful perspective to the industry. More useful still would be a technical assessment of international yards that would provide U.S. industry competitors with some idea of the gaps they must overcome. This information would need to be available to any U.S. competitor who requested it.

There will be a serious need to monitor the many ways other governments subsidize their shipbuilding industries. Because financial mechanisms and subsidies have played a major part in competitive position for decades, the single most important function of MARAD would be to ensure reasonably accurate measurement of these subventions and subsidies in other shipbuilding countries.

Recommendation 6. ONR should continue support of NA&ME faculty through fellowships, research projects directed at Navy objectives, and to the extent possible, projects with commercial economic impact. Certainly, the economics of technology will be of overwhelming interest to the industry in the next decade. Relatively little study has been done of the economics of various available technologies. U.S. shipbuilders must achieve many fewer labor hours, shorten delivery schedules, and achieve greater precision in shipbuilding. To the extent that it falls within ONR's charter, achieving better understanding of the economics of technology around the world and of the differences between the economics of technology used in military versus commercial shipbuilding would be invaluable. Finally, a significant effort in process simulation at the level of the entire yard, including suppliers, material handling, fabrication, erection, and outfitting, would provide the least-cost approach needed for U.S. shipbuilders to reenter the market.

Recommendations for NA&ME Schools

Recommendation 7. NA&ME schools must become more involved with the U.S. shipbuilding industry through research in business-process, system, and ship-production technologies, as well as through soliciting support for these and other kinds of research. The schools should continue concentrating on subjects traditionally taught but should turn much greater attention to the economic health of the industry. The future of NA&ME faculties depends very much on the health of the industry for the next decade or two, yet the schools appear to have few efforts under way to ensure the industry's health. Universities, with their multiple disciplines, led by the naval architects and marine engineers who justifiably lay claim to being good systems thinkers, should be able to seize the problem that U.S. shipbuilders face, understand what it will take to create a healthy industry, and reach as far afield as needed to understand the cultures, political motivations, and economic infrastructures of international competitors. The committee hopes that this talented group of academicians will take the initiative.

Acronyms

ABC	activity-based costing
ABET	Accreditation Board for Engineering Technology
ARPA	Advanced Research Projects Agency
ASEE	American Society for Engineering Education
ASTM	American Society for Testing and Materials
ATC	Affordability Through Commonality (NAVSEA program)
BMP	Best Manufacturing Practices (U.S. Navy program)
CAD/CAM	computed-aided design/computer-aided manufacturing
CCF	Capital Construction Fund (federal shipbuilding assistance program)
CDS	Construction Differential Subsidy (federal shipbuilding assistance program)
CIRRs	commercial interest reference rates
CNC	computer numerical control
DWT	deadweight ton
FAR	Federal Acquisition Regulations
GRT	gross registered ton
IEEE	Institute of Electrical and Electronics Engineers
IMO	International Maritime Organization
ISO	International Standards Organization

LAN	local area network
LNG	liquid natural gas (carried by special ships)
LOTS	logistics over the shore
MANTECH	Manufacturing Technology program
MARAD	Maritime Administration
MARITECH	Maritime Systems Technology program (ARPA program)
MIT	Massachusetts Institute of Technology
MSNAP	Merchant Ship Naval Augmentation Program
NA&ME	naval architecture, marine engineering, and ocean engineering
NAVSEA	Naval Sea Systems Command
NC	numerically controlled
NIST	National Institute of Standards and Technology
NMEI	National Maritime Enhancement Institute
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NRC	National Research Council
NSF	National Science Foundation
NSRP	National Shipbuilding Research Program
OBO	oil, bulk, or ore carriers
ODS	Operating Differential Subsidy (federal ship operation assistance program)
OECD	Organization of Economic Cooperation and Development
ONR	Office of Naval Research
R&D	research and development
RO/RO	roll-on/roll-off unitized cargo ship
SBD	system-based design
SNAME	Society of Naval Architects and Marine Engineers
SSC	Ship Structure Committee
SSTDP	Sealift Ship Technology Development Program
SWATH	small waterplane area twin hull
TAG	Technical Advisory Group
TRP	Technology Reinvestment Project (ARPA)
UNO	University of New Orleans
VLCC	very large crude carrier
WAN	wide area network

APPENDICES

APPENDIX A

Biographies of Committee Members

John M. Stewart is a director of McKinsey & Company. Mr. Stewart has specialized in solving problems for international technical companies in merger and acquisition, project management, management information systems, and research and development. He has served on many boards and commissions, including the Joint Council on Economic Education, the New York State Commission on Management and Productivity, and the U.S. National Commission on Productivity and was vice chairman of the Manufacturing Studies Board Committee for the Study of Defense Manufacturing Strategy. Mr. Stewart received a B.S. degree from Yale University and an M.B.A. from Harvard Business School.

Gerald J. Blasko is a construction superintendent at Newport News Shipbuilding. He was previously program manager for advanced technology and supervisor of manufacturing engineering. His previous employment includes Dravo Corporation, where he held a variety of positions in production planning and production engineering. Mr. Blasko received a degree of B.S. in industrial management from the University of Akron.

Edward J. Campbell, ***NAE***, retired as president of J.I. Case Co. Prior to that, he was president of Newport News Shipbuilding for 13 years. He is a past president of the Society of Naval Architects and Marine Engineers from which he also received the Admiral Land Award. He also served two terms as chairman of the Shipbuilders Council of America and is now a trustee of the College of William and Mary and Webb Institute of Naval Architecture. He is also a board director of Global Marine Inc., Zurn Industries, and the American Bureau of Shipping Group.

Mr. Campbell received a B.S. degree in mechanical engineering and an M.B.A. from Northwestern University.

Joseph J. Cuneo is a principal with MARINEX International, Inc., and with New York Bulk Carriers, Inc. He has served as chairman of the board and CEO of J.J. Henry Co., was co-founder, president and chief operating officer of Energy Transportation Corp., and president and chief operating officer of John J. McMullen Associates, Inc. He is a member of several professional and classification societies, including the Society of Naval Architects and Marine Engineers, where he is chairman of the Investments Committee; a member of the Executive Committee and the Finance Committee, the American Bureau of Shipping; and a member of the Board of Trustees of Webb Institute of Naval Architecture. Mr. Cuneo received a B.S. degree from Webb and an M.B.A. from Harvard Business School.

Arthur J. Haskell retired as senior vice president of Matson Navigation Company. Previous employment includes Western Gear Corporation, National Bulk Carriers, and commissioned service in the United States Navy. He is chairman of the Pacific Coast Committee of the National Cargo Bureau and has served as president of the Society of Naval Architects and Marine Engineers and as director of the San Francisco Bay Area Marine Exchange. Mr. Haskell is a graduate of the U.S. Naval Academy and received the graduate degree of Naval Engineer from the Massachusetts Institute of Technology.

Harold C. Heinze is a senior management advisor to Alaska Petroleum Contractors. He has served as resource development advisor to the governor of Alaska and as commissioner of natural resources for the state of Alaska. He was also president of ARCO Transportation company and president of ARCO Alaska, Inc. Mr. Heinze received a B.S. degree from Colorado School of Mines.

George H. Kuper is the president and CEO of the Council of Great Lakes Industries. He was previously CEO of the Industrial Technology Institute. Past positions include executive director of the National Center for Productivity and Quality of Working Life, executive vice president of the Boston Venture Management Co., deputy director of the Mayor's Office of Justice Administration in the City of Boston, and executive director of the Manufacturing Studies Board. He has been an advisor to the Center for Strategic and International Studies and the Council for Economic Development, chairman of the National Association of Manufacturers' Committee on Productivity, a founder and vice president of the American Productivity Management Association, and a member of the U.S.Chamber of Commerce Council on Trends and Perspective. Mr. Kuper received a B.S. degree from Johns Hopkins University, an M.B.A. from Harvard Business School, and a graduate degree from the London School of Economics.

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T. Francis Ogilvie is a professor at and formerly head of the Department of Ocean Engineering of the Massachusetts Institute of Technology. Previous employment includes the University of Michigan, where he was chairman of the Department of Naval Architecture and Marine Engineering, and the David Taylor Model Basin, where he was head of the Seaworthiness and Fluid Dynamics Division. He is a member of numerous professional societies, including the Society of Naval Architects and Marine Engineers, of which he is a fellow and recipient of the William H. Webb Medal, and the Society of Naval Architects of Japan. His service to organizations include the U.S. Coast Guard Academy Advisory Committee, and several committees of the National Academy of Sciences. Dr. Ogilvie received a B.A. from Cornell University, an M.S. from the University of Maryland, and a Ph.D. from the University of California at Berkeley.

Irene C. Peden, *NAE*, is a retired professor of electrical engineering at the University of Washington, Seattle, where she has also served terms as associate dean of the College of Engineering and as associate chair of the Department of Electrical Engineering. She recently completed service as director of the Division of Electrical and Communications Systems at the National Science Foundation. She is a member of several professional societies, including the Institute of Electrical and Electronics Engineers (IEEE) for which she is a fellow, and has served as vice president for educational activities, member of the Board of Directors and Executive Committee, Fellows Committee, Awards Board, and Editorial Board of the *Proceedings of the IEEE*. She is a member of the Engineering Development Council of the University of Colorado at Denver, the Electrical and Computer Engineering Department Advisory Board of the University of California at Santa Barbara, the Board of Visitors of the School of Engineering at Duke University, and the National Advisory Board of the GATEWAY Engineering Education Coalition. Dr. Peden served on the Engineering Societies' accreditation board for maritime colleges. She has received numerous awards, including the National Science Foundation's 1993 Engineer of the Year, the American Society for Engineering Education Hall of Fame, the Linton E. Grintner Award of the Accreditation Board for Engineering and Technology, and the Haraden Pratt Award of the IEEE. She is a former Chair of the Army Science Board. Dr. Peden received an M.S. from the University of Colorado at Boulder and a Ph.D from Stanford University.

Richard W. Thorpe is a principal consultant with Kværner Masa Marine, Inc. Previous employment includes the Shipbuilders Council of America, where he was vice president of export activities and technical research; John J. McMullen Associates, where he was executive vice president; Bath Iron Works, where he was contract administrator for all Navy programs; and Bethlehem Steel Corporation, where he was leader of the Nuclear Engineering Group. He is a lifetime member of the American Society of Naval Engineers and a member of the Society of Naval Architects and Marine Engineers, for which he is a member of the Technical and Research Steering, Production, Sealift, and Public Service Advisory committees. Mr. Thorpe received a B.S. from Webb Institute of Naval Architecture, a Nuclear Engineering Certificate from Oak Ridge School of Reactor Technology, and an M.B.A. from Harvard Business School.

John S. Tucker is retired vice president of engineering of National Steel and Shipbuilding Company. He is a member of the Society of Naval Architects and Marine Engineers, the Navy League, and the American Bureau of Shipping Technical Committee. Mr. Tucker earned a Higher National Certificate in Naval Architecture from Paisley Technical College.

Richard H. White is a research staff member at the Institute for Defense Analysis. He was formerly an economist with the Maritime Administration, and the chief economist of the Congress of the Federated States of Micronesia. He is a member of the American Economic Association and formerly a lecturer in microeconomics at Montgomery College. Dr. White received a B.A. degree from the Johns Hopkins University and an M.A. and a Ph.D. from the American University.

APPENDIX B

Presentations to the Committee

Torben Andersen, Odense Shipyard, Denmark, "Application of Automation in Shipbuilding and Ship Design"

Joachim Brodda, Bremer-Vulkan, "Automation in Shipbuilding"

Michael Cecere, Naval Sea Systems Command, "United States Navy Advanced Machinery System"

Ian Cuckneil, Braemar Developments LTD, "An Overview of the World New Building Market and What Owners Look for When Inspecting New Yards During Contract Negotiations"

David P. Donohue, The Jonathan Corporation, "The National Shipbuilding Research Program"

James A. Fein, Office of Naval Research, "ONR Perspectives on National Maritime Technology Needs"

Jose Femenia, Jr., State University of New York Maritime College, "The Education Committee of the Society of Naval Architects and Marine Engineers"

John Goodman, National Council of Economic Advisors, "Current Government Efforts to Aid Shipbuilding"

Albert Herberger, Maritime Administrator, "U.S. Maritime Administration National Shipbuilding Initiative"

David H. Hill, General Motors (retired), "Some Lessons Learned About the Application of Technology"

John Kaskin, Office of Naval Operations, "Dual-Use Ship for the Active RRF"

Kai Levander, Kværner Masa, "Marine Market Driven Processes to Develop Ships and Ship Systems" and "New Marine Transportation System Concepts and Technologies"

William W. Lewis, McKinsey Global Institute, "What Makes Industries Internationally Competitive?"

Thomas Lamb, Textron Marine and Land Systems, "World Shipbuilding Technology"

Christopher Lloyd, Kokums Computer Systems, "Impact of CAD/CAM/CIM on Shipbuilding"

David L. Luck, General Electric, "United States' Advanced Commercial Ship Propulsion Technology"

Anthony Manchinu, Total Transportation Systems, Inc., "Ship Production Systems as Used by Foreign Shipyards"

Michael F. McGrath, Advanced Research Projects Agency, "DoD Initiatives in 'Big M' Manufacturing"

Paul Mentz, Maritime Administration, "MARAD and Shipbuilding"

Robert F. O'Neill, American Waterways Shipyard Conference, "The Needs of Second-Tier Shipyards"

Frank Peterson, Office of Naval Research, "Shipbuilding in East Asia and Australia"

Charles Piersall, AMADIS, Inc., "ASTM and ISO—Partners for International Success—a 21st Century Necessity"

Ronnal Reichard, Structural Composites, Inc., "Application of Composites to Large Commercial Ships"

Nils Salvesen, Science Applications International Corporation, "Advanced Physics-Based Simulation Technology for Shipbuilding Industry, Operators and Regulatory Organizations"

George Sawyer, Sperry Marine, "Simultaneous Commercial and Military Manufacturing"

Robert W. Schaffran, Advanced Research Projects Agency, "The MARITECH Program"

Paul A. Schneider, Naval Sea Systems Command, "Navy Shipbuilding"

Bruce Scott, Harvard Business School, "Can Government Make Industry Internationally Competitive?"

Rod Vulovic, Sea-Land Service, Inc., "Importance of Technology—Ship Owner's Perspective"

Richard Woodhead, Shipkits International, "Application Issues in Foreign Shipbuilding Technology"

APPENDIX C

Making Financing Decisions in the U.S. Shipbuilding Industry

The committee recognizes that several factors could have a greater effect than technology on the competitiveness of the U.S. shipbuilding industry. These factors include financing, subsidies, international reputation, and the inherent difficulty of reentering into the international market. Although the assessment of these factors is beyond the scope of this study, given their importance, the committee has attempted to set this study within their larger context. This appendix briefly describes how financing decisions are made in the shipbuilding industry. This appendix is not intended to be more than an elementary presentation of shipbuilding finance. All shipyard managers certainly understand these basic financial principles and apply them on a daily basis. The important consideration is that a potential shipowner must consider much more than technology when purchasing a ship.

FINANCING

Terms of available ship financing are often a major factor considered by a potential ship buyer when determining where to place an order, especially when the terms are unique to a particular shipyard or shipbuilding country. In general, three factors define ship financing evaluation and selection: net present value (NPV), cash flow, and collateral requirements.

Net Present Value

To compare financing schemes, the shipowner performs NPV calculations for each alternative, discounting the cash outflow required to pay interest and debt amortization at a rate that reflects the cost of capital or opportunity costs (the rate of return available through other investments). The shipowner will usually consider the alternative with the lowest NPV to be the most favorable. Typically, the lowest NPV is associated with financing that allows the shipowner to borrow the greatest percentage of the price, to be repaid over the longest period of time, at the lowest available interest rate and origination cost. At this time, U.S. Title XI loan guarantees can offer the best terms available worldwide, with loans of up to 87.5 percent of acquisition cost for as long as 25 years at fixed interest rates closely approaching those of U.S. Treasury bonds. It is expected that this competitive advantage will disappear when the recently announced financing agreement of the Organization for Economic Cooperation and Development (OECD) is fully implemented.

While at first glance the alternative with the lowest NPV is the best, there are other considerations. Beyond price and delivery, they include interest during construction, owner's supervision and plan review, attendant legal and underwriting costs, and other expenses included in the owner's total acquisition cost (capitalized cost).

Cash Flows

Cash flow considerations can lead a shipowner to select a financing scheme that does not have the lowest NPV. For example, if all debt repayments are delayed for three years, the shipowner may prefer this alternative (particularly if buying in a "down market"), even though total payments will be greater over time. The owner will consider manner of debt amortization, whether in equal annual principal amounts; "level debt" payments (like a typical home mortgage); or low amortization in the early years with a "balloon" payment at the end of the financing term.

Collateral Requirements

The collateral required of the shipowner by the lender will also be a major consideration in evaluating financing alternatives. One lender might require detailed financial information on all the owners of a vessel and personal as well as extensive corporate assurances or guarantees. Assignment of revenue streams from charters or other vessel-employment arrangements might also be required. Another lender may be satisfied simply with the ship as collateral for the loan, with few additional requirements. The potential variations and permutations are endless and play an important part in the shipowner's evaluation process.

CONCLUDING COMMENTS

This appendix has briefly considered a few aspects of ship financing. There are certainly more considerations, including the tax structure of ship financing, which may affect decisions of U.S. and foreign shipowners. The degree to which foreign governments offer tax incentives for financing ship construction is another consideration in international competitiveness. The ability to offer ship acquisition financing through the Title XI program may offer U.S. yards a significant competitive advantage until the new OECD financing agreement is implemented. Ratification of the OECD agreement is the subject of pending legislation in Congress. Title XI allows the financing of a greater part of the shipowner's capitalized cost for a longer period of time at fixed interest rates lower than are generally available through other international ship financing alternatives.

APPENDIX D

Government and Industry Programs that Invest in Shipbuilding Technology

The second task of the committee is to assess current and proposed programs that invest in ship design and production-related research and to identify appropriate changes that would improve their effectiveness and contribution to the goal of creating an internationally competitive U.S. shipbuilding industry. Information on these programs came from several sources. Committee members and government liaisons to the committee were asked to identify all relevant programs. The Marine Board staff interviewed the program managers of the identified programs and obtained literature on the objectives of these programs. Interviews were also used to identify additional programs, for which information was then obtained. In addition, program managers and sponsors addressed the committee at its meetings. The following information on existing programs is based on those presentations, interviews, and other available documentation.

The following programs were assessed by the committee:

- Maritime Systems Technology
- Technology Reinvestment Project
- Simulation-Based Design
- National Shipbuilding Research Program
- Navy Manufacturing Technology Program
- Best Manufacturing Practices Program
- Sealift Ship Technology Development Program
- Affordability Through Commonality
- Office of Naval Research Surface Ship Technology Program

- American Society for Testing and Materials
- International Standards Organization
- National Maritime Resource and Education Center

MARITIME SYSTEMS TECHNOLOGY (MARITECH)

The president's initiative for revitalizing the U.S. commercial shipbuilding industry tasked the Maritime Systems Technology Office of the Advanced Research Projects Agency (ARPA) with establishing a technology-development initiative to help shipyards become internationally competitive in commercial markets and thereby help preserve the industrial base for possible future national security needs (Clinton, 1993). ARPA is executing this program in collaboration with the Maritime Administration and the Office of Naval Research (ONR). This program, called MARITECH, is structured for a five-year period, with $30 million in the first year, $40 million in the second year, and $50 million per year for the next three years.

The ARPA approach for MARITECH technology development consists of an integrated two-part program. The initial phase will be to master the basics of commercial shipbuilding and enter the international market in the near term. The second phase is to provide a national infrastructure dedicated to continuous shipbuilding product and process improvement for the long term. The approach is to have the shipbuilding industry compete for government funds on a cost-share basis to assist in these development initiatives. The shipyards are encouraged to initiate partnerships with customers, suppliers, and technologists to develop a total system or "focused development projects" approach (Denman, 1994). Through a government *Broad Agency Announcement*, which only specifies areas of consideration and criteria for acceptability, proposals are solicited from industry. In this manner, the ideas for projects that come from shipbuilders themselves rather than from the government. Criteria for awarding funds include having a team that is effective in identifying a real market need, an innovative design concept to service that market, and a competitive approach for the detailed design and construction process that could be implemented in the near term (MARITECH, 1994).

Linked with this near-term effort must be a long-term effort to take advantage of lessons learned and to institutionalize continued advancement. The primary thrust of the long-term program is to put in place an integrated national infrastructure focused on maritime technology development. The objective is to ensure the long-term viability and growth of the U.S. shipbuilding industry through continuous product and process improvement in commercial ship design and construction.

The awards for the first year of the program were announced in May 1994. Twenty projects were funded (ARPA, 1994).

High-Speed Monohull Focused Technology Development Project

The objective of this project is the development of a high-speed monohull ship. The specific project objectives are (1) to develop innovative designs for fast commercial cargo and passenger ships, (2) to enhance worldwide U.S. commercial-shipbuilding competitiveness by reducing ship design and construction time and cost, and (3) to integrate commercial-shipbuilding capability and secure contracts for new ship types. Funding is $600,000 over a 24-month period. The performers are Bath Iron Works Corporation, Bath, Maine; General Electric Company, Schenectady, New York; Kværner Masa Marine, Inc., Annapolis, Maryland; and American Automar, Inc., Washington, D.C.

Medium-Sized Multipurpose Ship

The objective of this project is development of a medium-sized, multipurpose ship. This wide-beam, shallow-draft vessel is intended to service short and medium length ocean routes and smaller ports of the current ocean trade. Its high beam/draft ratio, cargo self-unloading, and high maneuverability capabilities make it ideal for this purpose. This project includes a concept design study that will incorporate enhanced propulsion and manning-reduction concepts with a detailed market study. The project is funded for $400,000 over a 24-month period. The performers are Halter Marine, Inc., Gulfport, Mississippi; Pacific Marine Leasing, Inc., Portland, Oregon; Connell Finance Company, Inc., Westfield, New Jersey; and Fisker-Anderson and Whalen, Seattle, Washington.

23,000-Ton Container/Bulk Carrier

The objective of this project is to develop a state-of-the-art, self-sustaining, 23,000-DWT multipurpose carrier for the dry-cargo market. The design will include a maximum-cubic-capacity cargo hold for grains, a structural design that enables alternate loading of ores, wide-hatch openings for container and unitized cargo, a long hold for pipes and other steel products, self-unloading of bulk cargo, cargo gear capable of handling containers and/or unitized and general cargo, a modernized engine room and controls, and an advanced bridge featuring integrated navigation and advanced communication systems. Funding is for $1 million over a 24-month period. The performers are Halter Marine, Inc., Gulfport, Mississippi; Connell Finance Company, Inc., Westfield, New Jersey; and Ishikawajima-Harima Heavy Industries, Ltd., Japan.

Multipurpose Dry-Cargo Ship Design/Process Development

The objective of this project is to develop a commercially competitive contract design for a multipurpose dry-cargo ship. This design offers a plan for the re-engineering and reorganization of the McDermott shipyard and applies it to the design of a dry-cargo ship. Further, it develops state-of-the-art concepts for improvements and innovations in ship construction. This offers penetration of a U.S. shipyard into the international commercial dry-cargo market sector, building of strategic alliances with overseas shipyards and suppliers, and implementation of state-of-the-art design and production tools at a U.S. shipyard. The project is funded for $3.9 million over an 18-month period. Performers are McDermott Operations Research, Alliance, Ohio; McDermott/B&W, Lynchburg, Virginia; University of New Orleans, New Orleans, Louisiana; Ishikawajima-Harima Heavy Industries, Ltd., Japan; and MAN B&W, Germany.

Cruise Ship Preliminary Design, Manufacturing Plan, and Market Analysis

The objective of this project is to develop a cruise ship preliminary design and shipyard manufacturing plan. A market analysis will be prepared to determine the sales potential for U.S.-built cruise ships. The completion of this project will place Ingalls in a position to enter the competition in the multimillion dollar per year new cruise ship construction market. In addition, the project will better position Ingalls to compete in the cruise-ship repair market. Advanced ship designs, market validation, and creative construction processes will be employed. This project is funded for $1.1 million over a 16-month period. The performers are Ingalls Shipbuilding, Inc., Pascagoula, Mississippi; Hopeman Brothers, Inc., Waynesboro, Virginia; Jamestown Metal Marine Sales, Inc., Pompano Beach, Florida; Cruise Lines International Association, New York, New York; Deltamarin, Finland; and Aeromarine, Ltd., Greece.

U.S.-Built Cruise Ships: Market- and Producibility-Driven Design for the World Market

The objective of this project is the development of an advanced cruise ship design. Specific objectives of the project include capturing an appropriate share of the new cruise shipbuilding market by the year 2000; reestablishing the United States as a major player in the worldwide cruise/passenger shipbuilding industry; and taking a leadership role in developing and applying advanced propulsion, control, and environmental and safety systems for cruise ships. Funding is for $400,000 over a 24-month period. Performers are National Steel and Shipbuilding Co., San Diego, California; Delta Queen Steamship Company, New Orleans, Louisiana; General Electric Company, Schenectady, New York; Hopeman Brothers, Inc., Waynesboro, Virginia; Mercer Management Consulting, Lexington, Massachusetts; Argent Group, Ltd., New York, New York; and Kawasaki Heavy Industries, Ltd., Japan.

Commercialization of Planing Small Waterplane Area Twin Hull (SWATH) Technology

The objective of this project is commercialization of planing SWATH technology. This innovative vessel-design concept (planing SWATH), in combination with associated advanced construction technology, has the potential for global sales on a large scale. The integration of two technologies—planing craft and SWATH—in target markets such as ferries offers the opportunity of making small- to medium-sized marine craft faster in rough seas, more seaworthy, and more cost effective than current craft. The project is funded for $300,000 over a 24-month period. The performers are Halter Marine, Inc., Gulfport, Mississippi; Semi-Submerged Ship Corp., Solano Beach, California; Connell Finance Company, Westfield, New Jersey; and Hornblower Developer Corp., San Francisco, California.

Development of SLICE Fast Passenger Ferry Design and Comprehensive Marketing Plan

The objective of this project is to develop the design of a commercial high-speed ferry based on U.S. Navy-developed SLICE hull-form technology. This hull form offers a combination of high speed and excellent stability in heavy seas. These characteristics make it ideal for use as a high-speed ferry in open waters such as those in the Hawaiian Islands. The construction of these vessels will use advanced aluminum extrusion techniques to reduce construction time and cost. The proposers plan to conduct an extensive market survey and project a large international market for this type of craft. This project is funded for $400,000 over a 36-month period. Performers are Pacific Marine & Supply Company, Ltd., Honolulu, Hawaii; Lockheed Missiles & Space Company, Palo Alto, California; Textron Lycoming, Stratford, Connecticut; MacKinnon Searle Consortium, Ltd., Alexandria, Virginia; KaMeWa, Sweden; and Schichau Seebeckwerft, Germany.

Integration of Modern Manufacturing Methods and Modern Information Systems

The objective of this project is the integration of modern manufacturing and information methods in the revitalization of a state-of-the-market, medium-sized shipyard. The objective of the project will be to apply modern managerial design, material marshalling, and production techniques to the construction of jumbo-class ferries for the West Coast market. The project is funded for $1.6 million over a 36-month period. Performers are Todd Pacific Shipyards Corporation, Seattle, Washington; Kværner Masa Marine, Inc., Annapolis, Maryland; and Maritech Engineering Japan Company, Inc., Japan.

Penetrating the International Market for Small Ships

The objective of this project is to conduct a market analysis and to develop innovative designs for the international market in small vessels. In addition, the team will work to develop competitive build strategies and international financing packages for export sales. Kværner Masa Marine will also work with the shipyards on the team to develop a computer-integrated manufacturing system for the shipyards. The project is funded for $600,000 over a 24-month period. The performers are the American Waterways Shipyard Conference, Arlington, Virginia; Bender Shipbuilding, Inc., Mobile, Louisiana; Bird-Johnson Company, Walpole, Massachusetts; McDermott Marine, Amelia, Louisiana; Steiner Shipyard, Inc., Bayou La Batre, Alabama; Trinity Marine Group, Gulfport, Mississippi; Wartsila Diesel, Inc., Annapolis, Maryland; Kværner Masa Marine, Annapolis, Maryland; Colton and Company, Arlington, Virginia; SPAR, Annapolis, Maryland; and National Ports and Waterways Institute, Arlington, Virginia.

Sea Horse—Self-Elevating Offshore Support Platform for the International Markets

The objective of this project is to develop designs for self-elevating offshore support platforms for the international market. These designs will meet international requirements for permanent offshore structures, and the resulting platforms will be classified as ocean-going vessels. Possible applications for these versatile designs include subsea well service and maintenance, offshore construction, undersea pipe laying and maintenance, and oil spill recovery, drilling, and salvage operations. The project is funded for $1.5 million over a 24-month period. The performers are Bollinger Machine Shop and Shipyard, Inc., Lockport, Louisiana; Halliburton Energy Services, Inc., Dallas, Texas; Colton & Company, Arlington, Virginia; and Brown & Root, Inc., Houston, Texas.

Focused Technology Development, 40,000–DWT, Double-Hull Product Carriers, 85,000–DWT Double-Hull Oil, Bulk, or Ore (OBO) Carriers

The objective of this project is to develop 40,000-DWT double-hull product carriers and 85,000-DWT double-hull oil, bulk, or ore carriers. This project includes marketing and financial planning, expansion of computer-aided design/ computer-aided manufacturing capability, procurement of internationally competitive designs and their modification to the marketing analysis, production and manufacturing modernization, technology transfer, and training. The project is funded for $3 million over 36 months. The performers are Alabama Shipyard, Mobile, Alabama; American Automar Inc., Washington, D.C.; American Petrobulk, Inc., Washington, D.C.; and Burmeister & Wain, Denmark.

Focused Technology Development

The objective of this project is to develop a world-class design for a 40,000-DWT product carrier. This project includes a detailed market analysis and financial planning and the purchase of a design from an internationally competitive foreign yard. The design will be further modified to meet the requirements of the market analysis. This international competitive design will be examined for benchmarks for future design work. Avondale will negotiate a technology transfer agreement with an internationally competitive shipyard to obtain benchmarks for production processes. Metrification and standardization studies will also be performed. This project is funded for $2.3 million over 24 months. The performers are Avondale Industries, Inc., New Orleans, Louisiana; Dyer, Ellis, Joseph & Mills, Washington, D.C.; Chemical Bank, New York, New York; Canadian Imperial Bank of Commerce, Canada; MCA Associates, Greenwich, Connecticut; Carderock Division, Naval Surface Warfare Center, Carderock, Maryland; John J. McMullen, Associates, Inc., New York, New York; Kirby Corporation, Groves, Texas; American Heavy Lift Shipping Co., Houston, Texas; Mitsubishi Heavy Industries, Japan; Mitsubishi International Corp., New York, New York.

Petroleum Product Tanker Technology Development

The objective of this project is to develop petroleum product tankers for the domestic market. This consortium consists of representatives from all major sectors of the maritime industry. Together they will design a tanker that is environmentally safe and economically sound. Information will be exchanged throughout the consortium through a sophisticated electronic data exchange system. The project is funded for $800,000. The performers are Gibbs & Cox, Inc., Arlington, Virginia; Ingalls Shipbuilding, Pascagoula, Mississippi; Trinity Marine Group, Gulfport, Mississippi; Marine Transport Lines, Inc., Secaucus, New Jersey; Sabine Towing & Transportation, Company, Inc., Groves, Texas; Chevron Shipping Company, San Francisco, California; ARCO Marine, Inc., Long Beach, California; American Bureau of Shipping, Houston, Texas; University of Michigan, Ann Arbor, Michigan; Sperry Marine, Charlottesville, Virginia; Booz, Allen and Hamilton, Arlington, Virginia; Ishikawajima-Harima Heavy Industries, Japan; Aquamaster Rauma, Inc., Finland; and ABB Industrial Systems, Finland.

Focused Technology Development for a Family of Double-Hull Tankers

The objective of this project is to develop the designs and marketing and finance plans for 324,000-DWT and 125,000-DWT double-hull tankers. These tanker designs would be based on the Marc Guardian curved plate hull concept, which has been developed jointly by Marinex and Metro Machine. Construction of these vessels will pursue advanced technologies in the hull coating and a three-way welding process developed by Metro Machine and Lincoln Electric. The design and construction methods used in production offer potential owners the benefits of reduced construction times and reduced operating costs. The project is funded for $1.8 million over an 18-month period. The performers are Marinex International, Hoboken, New Jersey; Metro Machine Corporation, Chester, Pennsylvania; Ingalls Shipbuilding, Pascagoula, Mississippi; CG International, Inc., Scott Plains, New Jersey; Ross/McNatt Naval Architects, Stevensville, Maryland; Carderock Division, Naval Surface Warfare Center, Carderock, Maryland; American Bureau of Shipping, Houston, Texas; Webb Institute of Naval Architecture, Glen Cove, New York; Crandall Dry Dock Engineers, Inc., Chelsea, Massachusetts; General Electric Company, Schenectady, New York; Exxon Company, International, Florham Park, New Jersey; ARCO Marine, Inc., Long Beach, California; Texaco, Inc., White Plains, New York; Coastal Marine Corporation, Houston, Texas; Overseas Shipbuilding Group, New York, New York; Marine Engineers Beneficial Association, Brooklyn, New York; and Papachristidis (UK) Ltd., England.

Internationally Competitive, High Technology Tanker Vessels

The objective of this project is the development of innovative world-class designs for 40,000-DWT and 125,000-DWT tankers. This project includes a detailed market analysis; design development; double-hull tanker procurement and production technology transfer; review of environmental and safety features of tanker designs and machinery; marketing and financing plans; and design, engineering, and production tools and software. The project is funded for $1 million over an 18-month period. The performers are Modular Tanker Consortium, Annapolis, Maryland; McDermott, Inc., Amelia, Louisiana; BethShip–Sparrows Point, Sparrows Point, Maryland; Wartsila Diesel, Annapolis, Maryland; Bird-Johnson Company, Walpole, Massachusetts; Seaworthy Systems, Essex, Connecticut; Kværner Masa Marine, Annapolis, Maryland; SPAR, Annapolis, Maryland; International Marine Software Associates, Stevensville, Maryland; Wilson, Gillette & Company, Arlington, Virginia; and ABB Industrial Systems, Finland.

Market- and Producibility-Driven Shuttle Tanker Design for the World Market

The objective of this project is to develop state-of-the-art designs for a range of shuttle tankers of about 70,000-DWT to 125,000-DWT cargo carrying capacity. These tankers will have the ability to operate year round in a variety of weather conditions and in coastal, open ocean, and U.S. territorial waters. The design provides advanced state-of-the-art features such as a flexible propulsion plant, dynamic positioning capability, global positioning and collision avoidance features, and safety and environmental systems. In addition, adaptation of the designs will allow operation in Arctic and sub-Arctic environments. Features for high-latitude navigation will include ice avoidance, hull strengthening for operation in northern waters, superstructure and rigging de-icing, and design considerations for high seas and high wind conditions. The project is funded for $200,000 over a 24-month period. The performers are National Steel and Shipbuilding Co., San Diego, California; ARCO Marine, Inc., Long Beach, California; Wartsila Diesel, Mt. Vernon, Indiana; Raytheon Company Submarine Signal Division, Hudson, New Hampshire; IMODCO, Inc., Calabasas, California; First International Finance Corporation, New York, New York; KaMeWa AB, Sweden; Ugland Group, Norway; Braemer, England; and Kawasaki Heavy Industries, Ltd., Japan.

Conversion to World Class Commercial Shipbuilder

The objective of this project is to help Newport News Shipbuilding reenter the commercial shipbuilding market. This project comprises five complementary elements, including market analysis, applied state-of-the-art technologies, world-class production processes, innovative financial arrangements, and revised project management leading to construction of a 40,000-DWT tanker. The project is funded for $3 million over a 24-month period. The performers are Newport News Shipbuilding, Newport News, Virginia; Sabine Towing & Transportation Co., Groves, Texas; Texaco, Inc., White Plains, New York; Maritime Overseas Corporation, New York, New York; Science Applications International Corp., Arlington, Virginia; American Bureau of Shipping, Houston, Texas; Total Transportation Systems, A/S, Norway; Ishikawajima-Harima Heavy Industries, Japan; and MAN B&W Diesel, Germany.

Design of the Virtual Shipyard

The objective of this project is to create and utilize the development of a "virtual shipyard" to support the building of 40,000-DWT product carriers. The project includes the creation of a ship design development process that is fully integrated with marketing, design, and production engineering and the development of an integrated and efficient system for converting a shipbuilding contract into a delivered ship. This project could result in the building of an internationally competitive product carrier. The project is funded for $1.6 million. The performers are U.S. Shipbuilding Consortium, Greenwich, Connecticut; McDermott Inc., Morgan City, Louisiana; IBM Federal Systems, Manassas, Virginia; Westinghouse Electric Corporation, Sunnyvale, California; Microelectronics and Computer Technology Corp., Austin, Texas; George Washington University, Washington, D.C.; Carderock Division, Naval Surface Warfare Center, Carderock, Maryland; Kværner Masa Marine, Annapolis, Maryland; Colton and Company, Arlington, Virginia; and ARCO Marine, Long Beach, California.

From Sealift Ships to Vehicle Carriers Internationally Competitive Ships for the 1990s

The objective of this project is to develop a contract design, a build strategy, and marketing and finance plans for a vehicle-carrier vessel. The design of these vessels will include advances in modular design techniques, an integrated bridge, and workstation-oriented control systems. The shipbuilding process will use advances in modular construction and computer-integrated manufacturing. The project is funded for $200,000 over a 24-month period. The performers are National Steel and Shipbuilding Co., San Diego, California; Argent Group, Ltd., New York, New York; Kawasaki Heavy Industries, Ltd., Japan; and Kawasaki Kisen Kaisha, Ltd. (K-Line), Japan.

Second-Year MARITECH Proposals

The second year of the MARITECH program sought proposals for the development of market-oriented ship designs integrated with build strategies that can lead to competitive ship construction in one to three years. Technology development proposals were to be in the area of process-improvement technology that can dramatically improve ship design, construction, conversion, repair, and marketing processes that could make possible a revolutionary new process, heretofore limited by technology.

The overall objective of the second-year proposals is to dramatically improve overall efficiency in ship production. Proposals were also sought for product-improvement technology for shipboard equipment and systems that could dramatically improve operational performance and dramatically reduce operating, environmental liability, and life-cycle costs of U.S. built ships. As with the first year of MARITECH, proposals were sought from a vertically integrated consortia of shipbuilders, shipowners and operators, ship designers, equipment and material suppliers, universities, government and private laboratories, and other breakthrough technology developers.

TECHNOLOGY REINVESTMENT PROJECT

The Technology Reinvestment Project (TRP) is jointly sponsored by the Department of Defense, Department of Commerce, Department of Energy, NSF, National Aeronautics and Space Administration, and the Department of Transportation. The TRP is administered by the Defense Technology Conversion Council, which is chaired by the ARPA. The TRP mission is to simulate the transition to a growing, integrated, national industrial capability that provides the most advanced, affordable, military systems and the most-competitive commercial products. The TRP programs are structured to expand high-quality employment opportunities in commercial and dual-use U.S. industries and to enhance U.S.

competitiveness demonstrably (ARPA, 1993). Funding for TRP activities is cost shared with non-federal government entities.

The TRP began prior to MARITECH. Subsequent to the advertisement of the MARITECH program in 1994, all projects relating to shipbuilding became part of the MARITECH program. Of the 212 projects selected for the first TRP competition, two projects address shipbuilding and ship propulsion.

Commercial Shipbuilding Focused Development Project

The objective of this project is to transfer management and production technologies into the partnership to create a globally competitive shipyard. Specific technologies include computer-aided design and process simulation, advanced automated fabrication processes, flexible automation/robotics, real-time measurement systems for process control, production planning, material control and estimating, and pollution abatement. Advancement of these technologies and implementing them is intended to directly improve production of both commercial vessels and warships for the U.S. Navy. The total cost of this project is $13.9 million over a 24-month period. The performers are Bath Iron Works Corp., Bath, Maine; Great American Lines, Inc., Roseland, New Jersey; American Automar, Inc., Washington, D.C.; Kværner Masa Marine, Inc., Annapolis, Maryland; and Mitsui Engineering & Shipbuilding, Tokyo, Japan.

Demonstration and Spin-Off of the Integral Motor/Propeller Propulsion System

The objective of this project is the application of an innovative electric propulsion system originally developed for future U.S. Navy submarines to commercial marine applications. The system is known as the integral motor/propeller propulsor. The effort will include both factory tests and seawater trials. The propulsion system is expected to have a significant impact on the U.S. shipbuilding industry by providing advanced propulsor technology to compete against European and Japanese motors. These systems can also be incorporated into future U.S. Navy all-electric ships. The project is funded for $9.8 million over a 24-month period. The performers are Westinghouse Electric Corporation, Cheswick, Pennsylvania; Pennsylvania State University, State College, Pennsylvania; Edison Chouest Offshore, Inc., Galliano, Louisiana; Ben Franklin Technology Center of Western Pennsylvania, Pittsburgh, Pennsylvania; and Carderock Division, Naval Surface Warfare Center, Carderock, Maryland.

SIMULATION-BASED DESIGN

ARPA is developing the prototype of a tool that could enable a revolutionary change in the ship acquisition process (Jones and Hankinson, 1994). Simulation-based design (SBD) will seamlessly integrate, in real time, the resources of design and acquisition. The results of this program will provide the means for an interdisciplinary team to interact with a digital-based integrated product- and process-development model, enabling integrated and concurrent development of requirements, products, and related processes, such as manufacture, operations, and support. The SBD program will provide real-time connectivity to all of the activities of the acquisition process. The program will develop innovative human-computer interfaces beyond visualization. It will also incorporate intelligent design guidance and assistance, relating what have traditionally been unrelated areas of information.

The SBD program has two phases, the first of which began in March 1993 and was completed in June 1994. The first phase established the feasibility and potential of the proposed system. Phase One included demonstrations such as one illustrating the ability to show the structural response of the hull to a particular sea state through integrated physics models of a synthetic ocean and a ship-hull structural model. In another demonstration, data were taken from a computed-aided design model to a virtual environment where the data were manipulated and then returned seamlessly to the design model. In another demonstration, a piece of shipboard machinery was defined along with associated piping in a manner that, when the machinery was relocated in the design process, the piping was automatically rerouted along the optimum path, avoiding obstructions.

The second phase of SBD began in the second quarter of 1995. In this phase, critical technologies will be developed and integrated in a prototype system. The technologies that will be addressed include visualization and sensualization of data, tactile feedback, object-oriented database management, data standards, information baselines for distributed environment, wide-area network bandwidth, multilevel security, and information technology.

Phase One of the program, which was funded for $10 million, was performed by two teams. The first team consisted of General Dynamics/Electric Boat Division, Deneb Robotics, Loral Federal Systems, Intergraph, STEP Tools, Silicon Graphics, and the University of Iowa. Performers on the second team were Lockheed Missiles and Space Company, Newport News Shipbuilding, Science Applications International Corporation, and Fakespace. Phase Two is funded for $45 to $60 million in the president's budget over four years.

NATIONAL SHIPBUILDING RESEARCH PROGRAM

The mission of the NSRP is to assist the U.S. shipbuilding and repair industry in achieving and maintaining global competitiveness with respect to quality, time, cost and customer satisfaction (NSRP, 1993). The NSRP is an industry-driven, industry-led program administered through the Ship Production Committee of the Society of Naval Architects and Marine Engineers and the Carderock

Division of the Naval Surface Warfare Center. Funding is currently provided by ARPA's Maritime Systems Office. Additional financial support is provided by shipyards, design agents, and government agencies through the time invested by individuals in planning, managing, and reviewing the research performed by the eight panels of the NSRP.[1] Through industry involvement in the selection and management of projects, the NSRP ensures that the work is relevant to the needs of the shipbuilding and ship-repair industry (Donohue, 1994).

Panel 1: Facilities and Environmental Effects

This panel has two objectives, the first of which is to help the shipbuilding industry maintain compliance with environmental laws and regulations in a cost-effective manner and with the minimum impact to production. The second objective is to ensure that the production facilities of shipyards do not hinder essential improvements. To accomplish these objectives, the panel facilitates effective communication and information exchange within the shipbuilding industry and helps shipbuilders become aware of both current and future rules and regulations and the potential impact they may impose on shipbuilding operations. Current research projects include environmental symposia for shipyard managers, supervisors, and environmental compliance personnel; an environmental bulletin board with updates of federal regulations; and various environmental studies and testing program projects. Other projects include a study funded by the Environmental Protection Agency to evaluate and quantify emissions from dry-dock blasting operations that documents the reduction of emissions through paint reformulations required under the California marine coatings rules. The panel also tries to ensure that federal and state environmental regulations are in fact "livable." The panel works with the Environmental Protection Agency on Clean Air Act guidelines to educate both regulators and shipyards.

Panel 3: Surface Preparation and Coatings

This panel addresses the preparation and coating of surfaces of steel, aluminum, exotic metals, plastic, wood, and similar materials. These surfaces are on hull structure, pipe, cable, duct, equipment, furniture, and numerous other items on a ship. Protective, decorative, and special-function coatings are studied; for example, coatings that are anti-fouling, anti-corrosive, and anti-sweat; heat-resisting, camouflaging, lining, and insulating; nonconducting; conducting; temporary; and so on. More than a hundred different coatings may be specified for a typical U.S. Navy ship. Panel 3 is concerned with specifications, receipt inspection of materials, preparation for coating, application of coatings, personnel

[1]The eight panels are numbered 1 and 3 through 9.

protection, cleanup, and environmental compliance. The panel also addresses the difficult health and environmental challenges facing the surface-preparation and coatings discipline. These regulations can adversely affect construction costs and product performance. Research of the panel includes solving problems with specific coatings and other coatings-related problems. The research is of a very practical nature and most often produces an immediately implementable result.

Panel 4: Design/Production Integration

This panel addresses improving production through innovative design and planning methods and the recognition and correction of design methods that inhibit production. Panel 4 also conducts research into the means of integrating the design and production processes of U.S. shipbuilders so as to reduce costs, reduce production time, and improve quality. In addition, the panel evaluates worldwide research efforts and state-of-the-art shipbuilding and design with the intent of analyzing and modifying them as necessary and implementing these global efforts into American shipbuilding. Examples of successful research include studies on the application of advanced measuring techniques and scheduling programs to data and configuration management; a study on weld shrinkage; an assessment of computer aids in shipbuilding; developing a generic-build strategy; and other in-depth research evaluating aspects of producibility in shipbuilding. At the direction of the Ship Production Committee, the panel has expanded the scope of its research projects to include an international market study for U.S. shipbuilding, a joint project with Panel 8 on improving the U.S. shipbuilding industry's competitive position through use of concurrent engineering, and an assessment of the requirements for global shipbuilding competitiveness.

Panel 5: Human Resource Innovations

The research program of this panel is designed to develop and test specific human-resource innovations in shipbuilding and ship-repair environments. This panel is unique in that both union and management representatives participate in all aspects of the panel. The panel's research has included organizational topics, such as problem-solving teams; decentralizing statistical accuracy control responsibility to the ship production work force; multiskilled, self-managing work teams in a zone construction environment; and a study of a product-oriented work force. The panel also conducted a study for improving motivation in the shipbuilding industry through employee involvement, along with research on employee involvement in a shipyard assembly yard and an analytical review of employee involvement and work redesign in U.S. shipbuilding. Additional research projects have addressed safety issues, such as a study on organizational innovation in shipyard safety, a survey of the principal elements of shipyard safety programs, and a project on employee involvement in improving safety. Another project of this panel has been to organize periodic national workshops on human resource innovations in shipbuilding, bringing state-of-the-art information to a wide industry audience.

Panel 6: Marine Industry Standards

This panel is working to ensure that standards are developed or adopted for maximum benefit to the U.S. shipbuilding industry, considering that standards play an increasing role in the way the shipbuilding industry does business and in determining competitiveness and profitability as shipbuilding markets become more global and more commercial. Composed of managers and technical representatives from a wide spectrum of the industry, this panel has provided direction and much of the energy for the U.S. shipbuilding standards program. Working with Committee F-25 on Shipbuilding of the American Society for Testing and Materials (ASTM), the panel has initiated the development of more than 50 shipbuilding-related standards. More recently, the panel has turned to the broader issues of redefining the organization and processes by which the marine industry deals with standardization, both domestically and internationally. The panel conducted a Marine Industry Planning Workshop, bringing together the industry's standardization leaders to create a comprehensive plan for developing and administering industry-standardization strategy. Other recent projects include drafting a new industrywide Standards Master Plan, creating a computerized compendium of standards, developing a manual for establishing and managing a shipyard standardization program, and providing support to the U.S. Technical Advisory Group to the International Standards Organization (ISO). In addition, the panel conducted a project on introducing metrification into the shipbuilding industry, which is essential to global competitiveness. Other initiatives will address the acceptability of foreign and international standards in U.S.-flag applications and establishment of an industrywide communications network for standards information.

Panel 7: Welding

This panel addresses methods and processes for improving the technology of welding, cutting, forming and burning as it pertains to and is applied by shipyards in the United States. The panel also investigates new materials and inspection methods that will improve shipbuilding technology and efficiency. The scope of the research of the panel includes of all attributes of a weld system, including materials, machinery, technology, and the quality of the product. Research has included equipment development, filler-materials research and application analysis, and base-material metallurgy and weldability studies. The panel has also completed projects related to advanced processes and automated welding systems. Weld inspection technology development and fitness-for-purpose data collection have also been topics of study. Other projects include the development of a portable

AC/DC welding power supply module; development of mechanized gas metal arc welding of light plate; investigation of tubular electrodes designed for submerged arc welding applications; development of flame bending of pipe for alignment control; a practical guide for flame bending of pipe; and a project that created three-dimensional plastic replicas of various weld discontinuities, along with a detailed guide to their use. Current projects include development of a portable tack welding device, development of a filler material for welding HLSA-100 steel, a portable pipe laser-beam cutting and welding system, and an evaluation and application of portable welding robotics.

Panel 8: Industrial Engineering

This panel addresses the planning, performance, and implementation of research and development projects to advance shipbuilding processes and systems. The goal is to develop and initiate implementation of equipment, procedures, technology, systems, and processes that reduce costs and improve competitiveness of U.S. shipbuilding and ship repair. The research projects aim to reduce shipbuilding design, acquisition, and production process times and costs and to improve quality through people and processes. A recent project investigated methods of improving production throughput in a shipyard, with the objective of increasing throughput to reduce the cycle time of ship production from concept to delivery. Another project addressed the use of personal computers as an aid in the production planning process, developing a personal computer-based model to serve as a tool to assist planning organizations in developing, updating, and revising schedules and in staffing facility utilization reports. Other projects include an industrial engineering workshop, a project on the reduction of non-value-added tasks, and a joint project with Panel 4 on implementing concurrent engineering.

Panel 9: Education and Training

This panel addresses the educational needs of the U.S. shipbuilding and ship-repair industry with the objective of advancing the state of the art of ship production and improving industry competitiveness. Research by the panel has included development of a textbook on ship production, a technical evaluation of a U.S. shipyard to implement state-of-the-art shipbuilding processes, a 45-lesson video series on basic naval architecture, an overview of interactive instruction for shipyard trades training, and the facilitation of the NSRP leadership's strategic planning meetings. Other research includes surveys and analyses of specific U.S. and foreign training programs and a textbook on engineering for ship production. A project to apply the latest technology in education to shipbuilding training has created an interactive video instruction lesson on "Arc-Drawn Stud Welding." This lesson will be demonstrated to shipyards to show the ease with which shipyard training departments can develop their own interactive courseware.

NAVY MANUFACTURING TECHNOLOGY PROGRAM

The Department of Defense established the Manufacturing Technology (MANTECH) program in the late 1960s, with the requirement that each service maintain a MANTECH program. The overall purpose of MANTECH is to support manufacturing needs so as to improve the nation's ability to provide affordable military equipment and to sustain that equipment for increased service lives cost effectively. Within the Department of the Navy, the MANTECH program is managed by the MANTECH office of ONR (ONR, 1993).

The U.S. Navy MANTECH program provides a mechanism for the development of enabling manufacturing technology in the form of new processes and equipment and for the implementation of this technology on Navy-weapon-system production lines. MANTECH funds are used when industry cannot or will not provide the needed capability in a timely manner. The Navy emphasizes the reduction of risk inherent in the transition from research and development to production as the primary consideration for a MANTECH effort. Other considerations are development of the enabling technology without which military systems cannot be effectively or economically produced, implementation of MANTECH efforts in the production of Navy weapon systems, and dissemination of manufacturing technology that has both military and commercial attributes (dual-use) to the commercial sector to stimulate industry's implementation of and investment in new manufacturing techniques.

Total funding for Navy MANTECH was $211 million in fiscal year 1994, funding of $267 million in fiscal year 1995, and funding of $253 million for fiscal year 1996 (Jenkins, 1993).

Navy MANTECH projects are evaluated and selected by the following criteria:

- They must provide a solution to a well defined Navy need.
- They must demonstrate technical feasibility.
- They must develop generic technology applicable to multiple weapon systems and dual-use.
- They may encompass technology development at risk levels beyond those normally assumed by industry.
- They must provide for timely implementation of anticipated benefits.

Project benefits may be realized through increased productivity or capability, increased process capability, improved reliability, or conservation of critical materials.

Centers of Excellence

The Navy MANTECH program established six centers of excellence to provide focal points for the development and technology transfer of new manufacturing processes and equipment in a cooperative environment with industry, academia, and Navy centers and laboratories. The center of excellence concept was developed to:

- Serve as a corporate residence of expertise in a particular technological area.
- Provide advice to the MANTECH program director concerning program formulation.
- Provide consulting services to both the U.S. Navy's industrial activities and industry.
- Facilitate the transfer of developed manufacturing technology.
- Develop and demonstrate manufacturing technology solutions for manufacturing issues identified by the U.S. Navy.

The six centers of excellence are discussed below.

Automated Manufacturing Research Facility

The Automated Manufacturing Research Facility in Gaithersburg, Maryland, is sponsored by the Department of Commerce's National Institute of Standards and Technology (NIST). The objective of the facility is to develop and deploy automated manufacturing technologies that can improve the competitiveness of both the civilian and defense industrial bases.

Center of Excellence for Composites Manufacturing Technology

The Center of Excellence for Composites Manufacturing Technology in Kenosha, Wisconsin, is sponsored by the Great Lakes Composites Consortium. The center represents a collaborative effort among industry, academia, and government to develop, evaluate, demonstrate, and test composites-manufacturing technologies.

Electronics Manufacturing Productivity Facility

The Electronics Manufacturing Productivity Facility, in Indianapolis, Indiana, is sponsored by Indiana University-Purdue University at Indianapolis; the Naval Surface Warfare Center, Crane Division; and the Naval Surface Warfare Center, Aircraft Division. The facility's research is a team effort among government, industry, and academia in the areas of electronics design, assembly, test, inspection, and rework, with an emphasis on the evaluation of electronics manufacturing equipment, processes, and materials.

National Center for Excellence in Metalworking Technology

The National Center for Excellence in Metalworking Technology in Johnstown, Pennsylvania, is sponsored by Concurrent Technologies Corporation.

The principal goal of the center is to help the Navy and defense contractors improve manufacturing productivity and parts reliability through research, development, demonstration, training, and education in advanced metalworking technologies.

Navy Joining Center

The Navy Joining Center, in Columbus, Ohio, is sponsored by the Edison Welding Institute. The center provides a national resource for the development of materials joining expertise and the deployment of emerging manufacturing technologies to Navy contractors, subcontractors, and other activities.

Center of Excellence for Advanced Marine Technology

The Center of Excellence for Advanced Marine Technology, in New Orleans, is sponsored by the Gulf Coast Region Maritime Technology Center of the University of New Orleans. Thrust areas of this new center will be practical measures that the U.S. maritime industry can take to become more competitive in the global market.

Typical MANTECH Programs

There are more than 60 specific MANTECH programs that have application to commercial shipbuilding, either directly through the stated objective of the program or because the program will aid shipbuilders to some degree in becoming internationally competitive even though it may have been developed for other purposes. A few of these programs, some of which have been completed, are described here.

Intelligent Weld Process

The objective of this program is to increase the productivity, quality and safety of U.S. Navy welding operations through the use of computer-aided robotic work cells. The Navy will be provided with a prototype robotic welding cell that can be controlled and set up off-line to allow for single item robotic welding. The system is known as the WELDEXCELL and will be delivered to the Puget Sound Naval Shipyard. The program, which has a $5.7 million budget, is being performed by the American Welding Institute.

Plasma Spray—Computer Numerical Control Integration

The objective of this program is to develop a method of eliminating much of the manual skilled labor and part setups used when the Navy refurbishes many metal parts, thereby increasing the effectiveness and consistency of the thermal-spray operation. In this project, plasma spray and computer numerical control technologies are integrated into an automated system for part repair and maintenance. This work cell contains integrated parts preparation, thermal spraying, parts finishing, and quality assurance. A stand-alone process-planning system was also developed. The project was funded for $3.6 million and was performed by the National Center for Excellence in Metalworking Technology.

Multi-Sensor Inspection System

The objective of this program is to provide a state-of-the-art, multi-sensor inspection system for complete dimensional measurement and analysis of complex surfaces and shapes of interest to the Navy. The program is funded for $800,000 and is being performed by Martin Marietta Energy Systems.

Portsmouth Fastener Workstation

The objective of this program is to develop a flexible manufacturing system equipped with the technology of highly controlled systems necessary for the efficient production of highly accurate, Level-1 threaded fasteners of various types and sizes for use on nuclear submarines. This project is funded at $1.7 million and is being performed by the Automated Manufacturing Research Facility.

Advanced Machine Tool Structures

The objective of this program is to investigate the application of new machine forms and control strategies for machine tools to U.S. Navy needs in machining complex-contoured parts. The project is focusing on an octahedral-hexapod tool concept such as the one being developed by the Ingersoll Milling Machine Tool Company. This revolutionary machine tool form combines parallel, kinematic-link manipulators (also known as Stewart platforms) with an octahedral machine frame to provide full six-axis machining capability and a machine structure that is extremely rigid and self-contained. The machine planned for study will have a work volume of 1 cubic meter and a spindle power of about 15 kW (20 hp). The project is funded for more than $100,000 and is being performed by the Automated Manufacturing Research Facility.

Plasma Spray Sensor Development

The objective of this program is to assess Navy requirements for inspection of thermal spray coatings, particularly on machinery components of the submarine fleet, and to identify a sensor or sensors capable of inspecting thermal spray coatings and ensuring their quality. The project is funded for $50,000 and is being performed by the Automated Manufacturing Research Facility.

Robotic Paint Removal

The objective of this program is to investigate the potential for using robotics, control systems, and sensor technology to support the development of low-cost, automated paint removal systems. These systems will reduce the impact of stringent environmental and human workplace regulations, which will soon eliminate most conventional paint removal processes. The project is funded for $85,000 and is being performed by the Automated Manufacturing Research Facility.

Mobility for Welding Automation in Ship Construction

The objective of this program is to explore the requirements of shipyards for welding automation, current practices in automated welding systems, and the potential of a demonstration project that would incorporate mobility over the large working volumes inherent in shipyard operations. The project was funded for $85,000 and was performed by the Automated Manufacturing Research Facility.

Automated Propeller Optical Measurement System

The objective of this program is to develop a high-speed, optical-inspection tool capable of automatically measuring, at low cost, the surface of a ship's propeller. In addition, the system will provide a reliable measurement database to validate propeller designs and serve as input to automated propeller manufacturing and repair processes. This basic-measurement robot will rapidly and automatically produce detailed surface measurement data via non-contact, three-dimensional optical sensing. This system will provide dimensional inspection of the propeller and dimensional data necessary to make propeller repairs. This project was funded at more than $15 million and was performed by Robotic Vision Systems, Inc.

Propeller Adaptive Machining System

The objective of this program is to develop, fabricate, and install a system that will be capable of machining monoblock propellers to near-final configuration. More accurate measurement and the adaptive automated control of the machining process developed in the automated propeller optical measurement system will be used in this project. The project was funded for $14.5 million and was performed by Robotic Vision Systems, Inc.

Automated LAN-Integrated Paperless Factory Modernization

The objective of this program is to provide highly interactive, user friendly, assembly/inspection instructions and test procedures. The network will support developing, updating and accessing instructions and procedures in a centrally maintained database. The program will also facilitate the integration of text and graphics imported from computer-aided design, digitized first article photographs, and specification drawings and tests. This project is being performed by Litton Amecom.

Computer-Integrated Focused Factory Management System

The objective of this program is to design, develop, and implement an open system architecture solution that is versatile and flexible—one that will serve as the communications information foundation for the overall computer-integrated manufacturing strategy. This program will replace current application systems and information technology that is of third-generation, legacy-system vintage. The current technology is inflexible, costly, difficult to maintain, and incapable of providing a sufficient level of integration to allow for the timely, accurate, cost-effective sharing of data. The project is being performed by Litton Amecom.

BEST MANUFACTURING PRACTICES

The objective of BMP, which was established and funded as part of the U.S. Navy MANTECH program, is to identify the best practices used in industry, to encourage industry to share these practices among themselves, and to work together toward a common goal of high efficiency and improved product reliability. The program is very broadly based, covering government laboratories, shipyards, and other facilities. However, the program also includes extremely diverse industry representation, from defense manufacturing companies to hotels. A collateral objective of BMP is to identify the problems industry is experiencing in an effort to resolve them. To accomplish these objectives, independent teams of government manufacturing experts are established to survey companies.

Company participation in a survey by a BMP team is voluntary. The survey covers only things a company wants to have reviewed. When the BMP team completes the surveys, a report is written and provided to the company for review and editing before publication. Copies of the final report are mailed to government, industry, and academia representatives throughout the United States. The report is also entered in the BMP database, which is easily accessible by computer. Points of contact within the companies are identified in both the written and online copies of the reports, so that direct company-to-company contacts can be made. It is then up to the companies to determine what information they are willing to share (BMP Program, n.d.). Some of the organizations surveyed recently include Alpha Industries Components and Subsystems Division, Methuen, Massachusetts; R.J. Reynolds Tobacco Company, Winston-Salem, North Carolina; Philadelphia Naval Shipyard, Hamilton Standard Electronic Manufacturing Center, Farmington, Connecticut; Marriott Crystal Gateway Hotel, Arlington, Virginia; and Stafford County Public Schools, Stafford County, Virginia (BMP Program, 1994).

A major step in improving the competitiveness and strength of the U.S. industrial base was to affiliate the Navy BMP program with NIST and the University of Maryland to form a Center of Excellence. The Center of Excellence for Best Manufacturing Practices was established in early 1994 to promote technology transfer and solve common problems faced by U.S. commercial and defense firms. By improving the use of existing technology, promoting the introduction of improved technology, and providing a noncompetitive means of addressing common problems, the center will be a major factor in countering the foreign competition that threatens America's survival as a major manufacturing nation. The center will be effective because the means has already been developed, proven, and is in operation today in the Navy BMP program and within the NIST Manufacturing Technology Center outreach program.

Four BMP satellite resource centers are also being established around the nation to meet the growing number of requests for briefings, training sessions, and information on the BMP program. The centers will be in Louisville, Kentucky; Minneapolis, Minnesota; Oak Ridge, Tennessee; and San Francisco, California. Among the goals of the new centers are to make small- to medium-sized manufacturers aware of and have them use what the BMP program offers. The centers are also charged with achieving a greater level of involvement with and support of institutions of higher education in the areas they serve.

SEALIFT SHIP TECHNOLOGY DEVELOPMENT PROGRAM

The Sealift Ship Technology Development Program (SSTDP) is a broad-based R&D effort managed by NAVSEA. The SSTDP started in response to the congressionally directed Fast Sealift Technology Development Program, funded in fiscal year 1990–1991 (NAVSEA, 1992). The program goal is to develop new concepts and technologies that can be applied to future sealift ships and merchant ships to enhance their operational capability and efficiency, while simultaneously reducing the life-cycle cost, particularly acquisition cost, of ships capable of performing the sealift mission.

The technologies/developments addressed by the total program include total ship concepts, alternatives for achieving quick convertibility of lift on/lift off cargo ships to roll on/roll off cargo ships and vice versa, improvements in ship production and design for production methods, better hydrodynamics, improved ship propulsion, equipment to increase cargo loading and unloading rates (including merchant ship replenishment), personnel-reduction concepts, improved structural configurations and materials, and logistics-over-the-shore (LOTS) improvements. The long-term efforts will also enhance joint service LOTS operations to satisfy U.S. Navy requirements. This program heavily involves U.S. industry, particularly shipyards, and includes participation by the U.S. Coast Guard and

MARAD to assure that the potential benefits of these technologies to commercial ship design and shipbuilding are realized. Three primary focus areas are (1) mid-term sealift improvements (post 2000), (2) long-term improvements (2010–2020) and (3) merchant ship naval augmentation program (MSNAP).

Mid-term improvements are envisioned to be incorporated into new construction vessels acquired to meet the requirement for recapitalization of the Ready Reserve Force established by the Department of Defense Mobility Requirements Study of January 23, 1992. The goal is to develop technologies leading to commercially viable "dual-use" ships that would be used in commercial trade in peacetime and would be available for military roll-on/roll-off ship use in time of national need.

Long-term improvements are intended for the 2010–2020 time frame, when most sealift assets will be due for replacement (fast sealift ships, maritime prepositioned ships, T-AH, and T-AVB).

MSNAP enables civilian personnel merchant ships to perform tasks in support of the Strategic Sealift Mission. This program develops prototype systems from service-approved and commercially available components. The elements of the program are to provide new militarily useful capabilities, improve ship performance envelopes, and increase crew efficiency through mechanization. These elements are necessary because merchant ships are designed to fill a narrow commercial need with the greatest feasible economy and require conversion to meet military needs.

The total appropriated and planned funding for this program for fiscal years 1993–1997 is about $55 million (Raber and Webster, 1994).

AFFORDABILITY THROUGH COMMONALITY

The objective of the Affordability Through Commonality (ATC) Program of the Naval Sea Systems Command is to develop, through the use of commonality, the means to design, build, and operate a fleet that is affordable within future budget restrictions without degrading performance or reliability (Cable and Rivers, 1992). The program was funded for $3 million in fiscal year 1993, $9 million in fiscal year 1994, and $17 million in fiscal year 1995. Efforts of the ATC program include increasing the producibility and supportability of naval ships, developing generic build strategies, developing new ship architectures, and working with industry to incorporate shipyard production processes into naval ship design. The program also works with the vendor base to design systems that are highly producible from a manufacturing standpoint. The ATC project is primarily composed of efforts involving low technical risk, extending proven construction experience using standard components and methods assuring technical reliability. The basis for most of the initiatives is repackaging existing equipment by function. Several of these efforts have real-world models to follow. Thus, the technical risk of developing a successful product is minimal. Development and implementation of the commonality techniques of equipment standardization, process simplification, and modularization are expected to produce a number of benefits (Rivers et al., 1993).

OFFICE OF NAVAL RESEARCH

Surface Ship Technology Program

There are several programs sponsored by ONR that enhance shipbuilding technology (Gagorik, 1994). Dual-use technologies are in the categories of "spin in" and "spin out," that is, commercially developed technologies of use to the military and military technologies of use to the commercial sector. One of these technologies is the $25-million advanced double hull project, which is built around the concept of the unidirectional stiffened double hull. The project is managed by the Carderock Division of the Naval Surface Warfare Center but has many participants from other government laboratories, as well as commercial organizations. Twenty-five percent of that project is in structural integrity areas; another 25 percent is devoted to predicting damage from grounding. Another principal area of the advanced double hull project is the affordability task, which seeks to reduce the cost of construction for naval and commercial ships.

The emphasis of the affordable composite structures project is on developing composite structures for U.S. Navy combat ships, although developments may have future use in commercial ships, especially weight-critical, high-speed vessels. Although no project within the program is devoted specifically to it, the use of commercial off-the-shelf equipment is encouraged in all dual-use technologies projects. This has the advantages of both reduced price for Navy use and enhancement of the market base for commercial equipment manufacturers. Alternatives to halon gas are being pursued in the advanced damage control systems project, and this and other fire-fighting concepts, such as the multiphase water-mist project, will have application for commercial ships. The fiber-optic–based damage control sensors may also have commercial applications.

Fuel cell technology provides the same high efficiency across the entire power band and does not emit pollutants, even when "dirty diesel" fuel is used. The advanced electrical systems project has strong commercial implications, as evidenced by the Electric Power Research Institute participation in a large TRP project to enhance electric power transmission efficiency and reliability. Other concepts within this project, such as electronic circuit breakers, superconducting motors and generators, and the contrarotating homopolar motor, may have eventual commercial application.

The regenerating diesel engine and composite-diesel, vertical-axis propulsor are all propulsion programs that will improve propulsive efficiency. Active magnetic sensor controls are being developed for combat and noncombat use. These have also generated interest from commercial owners who have to take ships into areas where there is a high risk of underwater mines, such as the Persian Gulf. Similarly, the electro-optic emissions monitoring project is being conducted for military purposes but is an area of interest to commercial television and radio stations, which have problems today with electromagnetic interference, which is increasing as more uses are found for radio signals.

The reliability-based structural design project will have a major impact on the structural design of both Navy and commercial ships. This project is linked to similar efforts of the SSC, which in turn supports the effort of the American Bureau of Shipping to develop new structural design criteria.

In summary, there are many projects within the surface ship technology program that have commercial implications. Those that have the greatest implication for international competitiveness in shipbuilding are the advanced double-hull program and advanced electrical-systems projects.

AMERICAN SOCIETY FOR TESTING AND MATERIALS

Organized in 1898, the ASTM has grown into one of the largest voluntary standards development systems in the world. ASTM is a not-for-profit organization that provides a forum for producers, users, ultimate consumers, and others with a general interest (representatives of government and academia) for meeting on common ground and writing standards for materials, products, systems, and services. From the work of 134 standards-writing committees, ASTM publishes standard test methods, specifications, practices, guides, classifications, and terminology. ASTM's standards encompass metals, paints, plastics, textiles, petroleum, construction, energy, the environment, consumer products, medical services and devices, computerized systems, electronics, and many other areas. ASTM headquarters has no technical research or testing facilities; work is done voluntarily by 33,000 technically qualified ASTM members throughout the world. More than 8,500 ASTM standards are published each year in the 68 volumes of the *Annual Book of ASTM Standards*. These standards and related information are sold throughout the world. Approximately 85 percent of ASTM's income is derived from the sale of publications, primarily from the standards produced by committees. Other income is derived from annual administrative fees (ASTM, 1993).

The federal government participates in many of the committees of ASTM. However, the ASTM committee most relevant to this report is Committee F-25, Ships and Marine Technology, the members of which include individuals from several government agencies, shipbuilders, ship design agents, shipowners, and suppliers of ship machinery and components. There are 12 F-25 subcommittees. These subcommittees address the subjects of structures, insulation processes, outfitting, computer applications, marine environmental protection, general requirements, electrical and electronics, machinery, piping systems, international standards and long-range planning.

INTERNATIONAL STANDARDS ORGANIZATION

ISO is a worldwide federation of national standards bodies from some 90 countries. It is a nongovernmental organization established in 1947. The mission of ISO is to promote the development of standardization and related activities in the world with a view to facilitating the international exchange of goods and services and to developing cooperation in the intellectual, scientific, technological, and economic spheres. ISO's work results in international agreements that are published as international standards. There are currently more than 200 ISO standards applicable to shipbuilding and about 119 specifically for shipbuilding (Piersall, 1994).

The financing of ISO closely reflects its decentralized mode of operation. The financing of the Central Secretariat derives from member body subscriptions (77 percent) and revenues from the sale of the organization's standards and other publications (23 percent). The subscriptions required of member bodies for financing the operations of the Central Secretariat are expressed in units and calculated in Swiss francs. The number of units each member body is invited to pay is calculated on the basis of economic indicators of gross national product and the value of imports and exports. The value of the subscription unit is set each year by the ISO Council.

Within the ISO, the Technical Committee for Ships and Marine Technology (TC-8) establishes international shipbuilding standards. The input from the United States comes from the U.S. Technical Advisory Group (TAG) to the ISO's TC-8. This organization is accredited and chartered by the American National Standards Institute, which is the U.S. member body to ISO. The focus of ISO (TC-8) is on ship design, shipbuilding, ship systems engineering, operation of ships, and marine environmental protection. The U.S TAG seeks to inform and involve the U.S. maritime industry in the process of international standards development and adoption through the ISO. The U.S. TAG is the U.S. maritime industry's representative to ISO (TC-8).

The ISO 9000 series quality standards are standards for the management of quality that are recognized throughout the world. To become registered and certified to ISO 9000, a company's quality control system must be audited by a qualified third party firm that is not part of the company's organization. Areas covered by the standards include receiving inspection, in-process inspection, final inspection, corrective action, metrology and calibration, process controls, control of purchases, production tooling used as media of inspection, work instructions, internal quality audits, training, and servicing. Registration is for a period of three years, with surveillance audits performed every six months (SNAME, 1994).

NATIONAL MARITIME RESOURCE AND EDUCATION CENTER

The U.S. Maritime Administration established the National Maritime Resource and Education Center in 1994 to assist the U.S. shipbuilding and allied industries in improving their competitiveness in the international commercial market. The center is intended to be a major source of information and facilitator within the government for the maritime industry, providing expertise, information, and reference material on commercial shipbuilding. The short-term focus of the center is on establishing a marine industry standards library; providing assistance to companies that wish to become qualified to ISO 9000 for quality assurance; conducting seminars and training; being an interface with the U.S. Coast Guard for implementing consensus standards in lieu of regulations; providing support to ISO (TC-8); coordinating with ARPA for the MARITECH program; updating the MARAD guideline specifications to include international standards and to reflect metric dimensions; developing a three-dimensional computer-aided design library; and providing marine environmental protection information. These short-term goals are part of a continuing process to acquire and maintain marine standards; develop and conduct seminars and workshops on a variety of topics such as standards, regulations and environmental concerns; and provide other information to assist industry (MARAD, 1994).

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APPENDIX E

Schools of Naval Architecture and Marine Engineering

The following schools offer degrees in naval architecture, marine engineering, or ocean engineering. All undergraduate curricula are accredited by the Accreditation Board for Engineering and Technology (ABET), unless otherwise indicated. There is no similar formal accreditation process for graduate programs.

The University of California at Berkeley Department of Naval Architecture and Offshore Engineering was established in 1958 as a graduate program. The establishment of the graduate program at that time was assisted by the Office of Naval Research (ONR). In 1981, an undergraduate degree program in naval architecture was established, but the department suspended this degree offering in 1995. Undergraduate students in the Department of Mechanical Engineering can enroll in a naval architecture option in the future. There are 12 students enrolled in the program under this revised arrangement.

The graduate program of naval architecture and offshore engineering at Berkeley offers degrees at the master's (M.S.), professional degree (M.Eng.) and doctoral (Ph.D. and D.Eng) levels. Approximately 10 graduate degrees are awarded annually, including two or three doctorates. The current enrollment is about 30 students, all of whom are full time students. As is the case in graduate engineering programs at most major universities, about one-quarter of the students are of international origin.

The faculty at Berkeley has the equivalent of three full-time professors. All are active researchers and consultants. Research activities, although few compared to other, larger faculties, span a variety of unique areas: nonlinear ship and offshore hydrodynamics, large flexible structure, wave-load prediction, cable dynamics, reliability-based design methods, and ship maintenance and repair engineering. Research funding has been provided by the ONR, National Science Foundation (NSF), National Oceanic and Atmospheric Administration (NOAA) Sea Grant and Multi-Sponsor Industry consortia. This department was selected as one of the four national institutes for maritime technology enhancement by the Maritime Administration. Despite a small faculty and student body, the department is regarded as being of high quality.

The California Maritime Academy was established in 1929 and has the mission of educating managers, engineers, and officers for marine-oriented industries. About 100 students a year enroll in the program, which leads to a degree of B.S. in marine engineering technology.

The Florida Atlantic University began in 1964. The Department of Ocean Engineering has an enrollment of nearly 200 students of whom perhaps one-quarter are part-time. An average of 20 undergraduate degrees have been awarded in the last several years. Some of the part-time students are participants in a cooperative plan that requires alternating periods of full-time work with periods of full-time study. Some classes are offered in the evening. About 15 master's degrees are awarded each year, and an occasional doctoral degree is also awarded. There are 20 faculty members in the department.

The Florida Institute of Technology was established in 1958 in conjunction with the U.S. space program. The Department of Ocean Engineering is one of seven departments within the College of Engineering. The department has about 100 undergraduate students and awards about 15 bachelor's degrees and three or four master's degrees. Occasionally the department awards a doctoral degree. Graduates gain familiarity with the design of ocean engineering systems along with physical oceanography and the fundamental engineering science courses. Research facilities include equipment for structural and pressure testing and a small wave tank. Research interests of the 10 faculty members include corrosion and materials, naval architecture and shipbuilding, and fluid dynamics.

The Great Lakes Maritime Academy is part of Northwestern Michigan College, a two-year school. About 10 students per year enroll in the program, which leads to an associate degree in marine engineering.

The Massachusetts Maritime Academy was established in 1891 as the Massachusetts Nautical Training School. Enrollment is about 650, of whom 40 to 60 students enroll every year in the program that leads to the degree of Bachelor of Science in Marine Engineering.

The Massachusetts Institute of Technology (MIT) first taught courses in marine engineering in 1886 and in naval architecture in 1888. In 1971, to reflect a change from a ship-systems orientation to involvement in a wider range of ocean systems, MIT changed the name of the Department of Naval Architecture and Marine

Engineering to the Department of Ocean Engineering. There are currently about 15 undergraduate students enrolled in the department. The undergraduate ocean engineering degree program is based on the concept that engineering education at that level should focus on the design of complex systems, integrating the propulsion, structural, or control, and many other concerns within the system configuration and on determining these elements with full understanding of the operational environment.

The graduate program at MIT is augmented by about 30 U.S. Navy and U.S. Coast Guard officers who are enrolled in the Naval Construction and Engineering Course (XIII-A). The department offers graduate studies in the fields of ocean engineering and naval architecture and marine engineering and awards master of science degrees in both. In addition, the department offers a Marine Environmental Systems program that leads to the degree of Master of Engineering in Ocean Engineering. Also available are the professional degrees of Ocean Engineer and Naval Engineer and doctoral degree programs (Sc.D. or Ph.D.). The naval construction and engineering program for Naval officers, Course XIII-A, leads to the Naval Engineer professional degree or the Master of Science degree, or both, when those seeking the Master of Science degree complete additional course work and a thesis acceptable for both. The ocean systems management program for students with solid engineering backgrounds who are interested in the business and management aspects of ocean engineering systems and activities leads to both Master of Science and doctoral (Ph.D.) degrees in ocean systems management. There is also a joint MIT-Woods Hole Oceanographic Institution program, part of a larger joint applied ocean science and engineering program that involves the application of physics and the engineering sciences to the study of oceanic processes and the design of instruments, systems, and structures required to observe, measure, and work in the oceans. A total of about 40 graduate degrees have been awarded in each of the last several years. The Department of Ocean Engineering at MIT currently has a faculty of 22 professors with specialties in the fields of public policy and law, hydrodynamics, dynamics, acoustics (including Arctic acoustics), ship and ocean systems, power systems, computer-aided design, ocean management, structural mechanics, and materials and fabrication techniques.

The research program at MIT is similarly diverse and extensive. ONR sponsors research in almost every subject area of interest to the faculty members and a dozen full-time research engineers. The Advanced Research Projects Agency (ARPA), NSF and several consortia from industry are the other principal sponsors of research at MIT. NOAA's National Sea Grant College Program also sponsors research at MIT. Hydrodynamics is the predominant category of various research efforts, many of which are fundamental research involving vorticity control, vortex dynamics, free-surface turbulence, and similar areas, but ship resistance and means for propulsion, ship motions and wave-induced loading, as well as the loading and the response of offshore structures, are also studied. Other significant areas of research include welding systems, scheduling problems in optimizing container shipping revenues, tanker safety, computational geometry, underwater acoustics, and structural dynamics.

The University of Michigan Department of Naval Architecture and Marine Engineering originated in 1881, when a U.S. naval officer was sent to the campus at Ann Arbor to teach courses in steam engineering and iron shipbuilding. This department grew rapidly and for many years granted more than half of the bachelor's degrees for naval architects and marine engineers in the United States. The current undergraduate enrollment is about 80 students. Approximately 25 degrees of Bachelor of Science in Engineering are awarded each year.

Graduate enrollment at Michigan is approximately 70. Of these, more than one-quarter are foreign nationals. In 1994, the eight graduate program areas of specialization in marine hydrodynamics, marine structures, marine engineering, marine environmental engineering, offshore engineering, marine systems management, ship production, and computer-aided marine design were combined to encompass the primary thrust areas of marine hydrodynamics, marine environmental engineering, and concurrent marine design. The degree of Master of Engineering is offered in the multidisciplinary field of manufacturing. This degree program, which will use the curriculum for concurrent marine design, is intended to prepare students for careers in the practice of engineering in industry. Other degrees offered are a joint degree of Master of Business Administration and Master of Science in Engineering, the degree of Master of Science in Engineering, and the degrees of Professional Engineer and Doctor of Philosophy.

Michigan's faculty consists of 14 members. Some of these individuals had some industrial experience prior to joining the faculty, including positions at shipyards or with the U.S. Navy. Areas of specialization include aspects of naval architecture and marine engineering, including both ship and offshore structures; resistance, motions, hydrodynamics; ship and offshore system design or computer-aided design in general; operations and management; production planning; and power plants and propulsors. Other areas of specialization are in branches of ocean engineering that deal with waves, sediment transport, and other topics relating to the physical conditions and processes of the oceans (coastal or nearshore engineering), and offshore engineering.

The Department of Naval Architecture and Marine Engineering has had sponsored-research funding equivalent to $150,000 to $200,000 per faculty member for the last several years. This may consist of more than two dozen actual contracts. Some professors have three or four contracts at any given time for which they are the principal or co-principal investigators, with some being carried on over a two or three year period. This level of effort has been sufficient to support about as many doctoral students as the faculty can adequately supervise (two or three doctoral students per faculty member) and many of the master's degree students as well. The larger contracts, which extend over several years and address subject matter and new problems commensurate with the sophistication and more theoretical treatment necessary for completing a doctoral thesis, are most desirable. Sponsors of research include the ONR University Research Initiative, ARPA, NOAA's Sea Grant College Program, and consortia with commercial corporations and organizations and government agencies.

The University of New Orleans (UNO) established the School of Naval Architecture and Marine Engineering (NA&ME), the second largest state university of the Louisiana State university system, in 1981. The lack of naval architects and marine engineers in the Gulf Coast region resulted in a petition by the marine industry for a school of naval architecture and a ship offshore laboratory that had a 125 foot-long towing tank. In 1984, the university awarded the first NA&ME degree. The nine-story engineering building, which houses a 125-foot by 15-foot by 7.5-foot towing tank and a large structures laboratory, was completed in 1987.

The 1994 enrollment was around 85 to 87 full-time undergraduate students and five or six part-time undergraduate students, and 10 to 15 graduate students. During the semester, a number of full time UNO NA&ME students work at part-time jobs in New Orleans naval architecture design firms as well as in the local shipyards. This is possible by scheduling most of the UNO NA&ME courses in the late afternoon or evening.

The UNO NA&ME faculty consists of four professors. All are active in research that is funded by ONR, NSF, Sea Grant and the Gulf Coast Region Maritime Technology Center, and industry projects. This research covers the areas of ship offshore structure design, hydrodynamics, seakeeping, marine engineering, and maritime operations.

The State University of New York Maritime College was established in 1874 to educate and train qualified people to become licensed officers in the American Merchant Marine. The school awards the degrees of Bachelor of Science and Bachelor of Engineering and has programs in marine engineering and in naval architecture. There is a graduate program leading to a Master of Science degree, but it is in transportation management. There are over 100 students currently in the two programs. More than 30 students receive the Bachelor of Engineering degree annually; most of these also earn their Third Assistant Engineer license. The school has no formal research program.

Texas A&M University at College Station offers a separate ABET-accredited undergraduate program in ocean engineering administered within the Department of Civil Engineering. There are about 100 students in the ocean engineering program. Seven Bachelor of Science degrees and about the same number of Master of Science and Master of Engineering degrees have been awarded in each of the last several years.

Texas A&M University at Galveston is a special purpose institution of higher education for undergraduate education in marine and maritime studies in science, engineering, and business for research in public service related to the general field of marine resources. There are programs in marine engineering, in which about 30 students enroll each year, and a program in naval architecture and marine engineering, in which about 20 students enroll annually.

The Virginia Polytechnic Institute and State University program in ocean engineering is part of the Department of Aerospace and Ocean Engineering and has an undergraduate enrollment of about 50 students (not including first-year students) and about 10 graduate students. The educational thrust is the preparation of students for the capstone preliminary ship or offshore platform design course, which is taken during the final year.

Four members of the faculty of the Department of Aerospace and Ocean Engineering teach ocean engineering. The research level at the university is generally of the same quality as at the other institutions discussed here; however, research is not nearly as extensive in the marine field because of the smaller number of investigators. Research is concentrated on ship structures and computer applications, and submarine hydrodynamics.

The Webb Institute of Naval Architecture, now known as Webb Institute, began teaching naval architecture in the Bronx, New York. The school was established under an endowment from William H. Webb, a successful shipbuilder, and that endowment, along with other gifts, enables the school to offer full-tuition scholarships to all students. The school moved to an estate at Glen Cove, Long Island, in 1947. Although the name of the school was recently changed to Webb Institute, the educational program is still directed toward undergraduate naval architecture and marine engineering.

Webb Institute admits 24 students every year, and the total enrollment is about 80 undergraduate students. The curriculum includes an eight-week winter work term, during which students engage in practical work at shipyards, aboard ship in the engine room, in design offices, or in course-related industries. There is currently no graduate program. Webb students must be U.S. citizens.

Webb has a faculty of about 10 professors and several research professors. Research is conducted through the Center for Maritime Studies in the fields of theoretical hydrodynamics, finite-element structural analysis, model tests, ship data collection, industrial engineering, management science, economic analysis, marine engineering, probability theory, and systems analysis.