Program Element 2.3

Advanced Vessel Technologies

P.E. 2.3.1.3 Develop Technical Plan for Development and Implementation of Advanced HSS Technology Systems

P.E. 2.3.2.3 Develop Technical Plan for Implementation of Advanced HSS Shipbuilding Technology

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1.0 Introduction

This report is a summary of the recommendations for research and development that have been generated as a result of a two-year study of the technology and technology needs in high speed ocean shipping. Together with the detailed reports covering Program Elements 2.3.1.1, 2.3.1.2, 2.3.2.1, and 2.3.2.2, this document draws together the findings on the effort defined in the statement of work. During the period covered by the study (FY 1998/1999) interest has increased in high speed shipping, and realistic performance objectives are being defined. A number of commercial ventures have been announced, although no fast commercial ocean shipping service currently exists.

Rapid movement of ocean freight is increasing in importance in the world of just-in-time manufacturing. As detailed in the previous sections of our report[*,f] however, there remain significant barriers to the implementation of high speed ocean cargo transportation. These barriers must be removed if high speed ocean shipping is to reach its potential in the movement of passengers and freight (personnel and materiel) in commercial and military markets.

The opportunity for fast ocean-borne freight is not limited to trans-oceanic services. Within smaller regional markets, such as the Caribbean, the Mediterranean, the North Sea, and Southeast Asia, rapid movement of goods and materials can have a profound effect on local economies. In North America, congestion on highways and railways substantially slows transfer of products along the East, West, and Gulf Coasts. There is thus a significant opportunity for a high speed ocean cargo service over both short and long distance routes.

Some observers expect that high speed cargo ships will simply be extensions of high speed ferries. While it is logical to expect that over short routes (e.g., San Francisco Bay) ro-ro cargo ferries may fill a niche, the long-term objective of this program is to establish trans-oceanic high speed cargo services. Because of the differences between this type of service and ferry service, it is unlikely that a simple extension of fast ferry technology will satisfy the conditions for successful commercial freight operations. In order to guide development of high speed ocean transportation in the next decade, we have prepared a road map of those actions which should be taken to accelerate the development of a domestically-based high speed cargo transportation industry, including shippers, ship designers and builders, and ship operators. The roadmap includes suggestions for specific programs that will support industrial activity in the area.

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[*] Program Element 2.3, Advanced Vessel Technologies, Program Element 2.3.1, High Speed Sealift Design Evaluation and Analysis, P.E. 2.3.1.1 Analyze and Evaluate High Speed Sealift Current Designs, P.E. 2.3.1.2 Analyze and Evaluate Current and Recent Research on High Speed Sealift Design Issues.
[f] Program Element 2.3.2 HSS Ship Construction Evaluation and Analysis, P.E. 2.3.2.1 Assess Global and Domestic Shipbuilding Requirements for High Speed Ship Systems, P.E. 2.3.2.2 Evaluate Barriers to High Speed Ship Fabrication

The information presented in this report focuses exclusively on the *commercial* market for high speed shipping. The definition of military requirements will augment commercial requirements, as the assumption is that the military will make use of commercial vessels in time of national need. Thus the first priority is the establishment of a commercial high speed ocean shipping service over a short distance (up to 1,000 nautical miles), to test both market assumptions and vessel technical performance under commercial operating conditions, as well as to determine what other operational barriers (e.g., regulations, port/intermodal problems, crew ergonomics) need to be addressed to successfully expand high speed shipping to intercontinental shipping routes. A parallel priority is a program to develop the technology to facilitate the expansion of this service to intercontinental shipping routes.

The technology development program recommended is primarily focused on attacking the major barrier to profitable operation of a high speed ocean cargo service: the high cost of energy required to propel ships at the speeds required over the distances required. In addition, a number of other areas that may impact high speed sealift operations are identified for further research.

2.0 Principal Findings

In our study we reached the following conclusions regarding high speed commercial ocean-borne cargo shipping:

1. There is a commercial market for such a service. It will draw from both current air freight and conventional ocean freight services.
2. Profitability of operation and expansion of this market is controlled by the cost of fuel required to power the ship, and by shipping rate structure. At present, the estimated fuel consumption on candidate ships is sufficiently high to jeopardize the profitable commercial operation of a high speed shipping service between Europe/Asia and the United States. This implies that more efficient propulsion systems must be developed and that lightweight materials should be substituted for heavier materials in ship construction.
3. The ship and the port facility must be integrated to minimize cargo load and unload time. Port/intermodal problems must be analyzed and addressed so that the advantage conferred by high speed shipping is not negated by delays moving goods to and from the port.
4. Extrapolation from current high speed ferry operations is a valid place to start development of a high speed cargo market. However, as passenger and passenger/vehicle ferries have different load and performance requirements than cargo vessels, direct extrapolation from fast ferry experience must be approached with caution.
5. Various hull designs may satisfy this application. The choice of hull form is dependent on many factors, including ship size, cargo load, and type of service intended. Selection of the optimum hull form cannot be made at the present time, as a number of hull forms continue to be actively under development. In addition, it should be noted that the optimum hull form for a specific application, such as coastal freight service, may not be optimum for other service, such as trans-oceanic trade. Wake wash concerns must be addressed in the assessment of hull forms. High speed ferries are often shallow draft vessels, subject to maneuverability in port and berthing problems in windy conditions. High speed cargo vessels can be shallow or deep draft. A number of designs under consideration emphasize slender hull forms and deep draft (~ 10 m). The integration of power plant (including transmission and propulsors) and hull form – essential for efficient operation of the craft – is expected to require significant development work.
6. The Maritech ASE program should be encouraged, as a way of establishing worldwide best shipbuilding practices in United States shipyards.
7. There are no barriers to construction of high speed ships that are unique to this type of craft, as long as current materials and processes are used and technology does not change. The requirement to decrease fuel usage implies that current ship construction materials (steel and aluminum) may have to be replaced by lighter weight advanced materials, such as intermetallics and composites. Should this happen, development of shipbuilding techniques for the use of these materials will be necessary.
8. Specific areas where shipbuilding techniques may require manufacturing development for high speed ships include coating technology, curing technology for large

composite hulls, joining technology, and inspection systems for large hull forms and joints between hulls, decking and superstructure.

9. An area of high priority that links ship design and construction is that of high speed data transfer and interchange between designers, shipyards, owners and classification societies.
10. Because high speed cargo ships will travel at freeway speeds, advanced ship control systems will be needed. Maneuverability and rapid deceleration are expected to offer particular challenges. Avoiding collisions with small craft is also a major concern. Many of these small craft, particularly in coastal areas, are not equipped to continuously report their position in weather conditions of reduced visibility, and, in the case of recreational vessels, their operators often fail to appreciate the maneuverability problems of high speed craft.
11. There are significant regulatory problems that must be addressed by classification agencies and civil (port and harbor) authorities that will affect the design, construction and operation of these ships.
12. The effects of prolonged exposure to operation of ships at high speed on the ability of the crew to perform its functions in an alert manner appears to have received inadequate study, and further research in this area is needed.

3.0 Recommendations

Based on our findings we recommend a two-level program to facilitate both technology and market development for high speed cargo shipping. The two levels are:

- **An immediate effort to build and operate a commercial high speed (over 50 kts) cargo ship using the best available current technology.**
- **A phased program of technical development to establish enabling technology for next-generation high speed cargo ships.**

As profitable operation of a high speed (speeds between 40 and 70 kt) cargo vessel does not appear to be feasible across the Atlantic or Pacific Ocean at present because the costs of high fuel usage, a smaller geographical area of operation is desirable for the initial service. Some natural markets for North America shippers are the Gulf of Mexico/Caribbean and/or coastal shipping routes on the East, West, or Gulf Coasts. There is significant congestion in land routes in these transportation markets, which creates an opportunity for a high speed water-borne shipping service.

The development of high speed ocean transportation in the United States must take into account a number of factors:

1. High speed ocean freight rates are projected to be higher than current ocean shipping rates, perhaps twice as high. The ships are expensive to operate because of the high cost of fuel required to move them through the water at high speed;[1,2] this increases their sensitivity to fuel prices. Nevertheless, high fuel costs do not appear to preclude profitable operation of commercial high speed cargo services, as a market does exist at shipping prices that are less than that of airfreight. Unfortunately, the price elasticity of this market has not been determined. The present study was limited to port-to-port transportation, and did not address the full logistical (factory to consumer) travel. To determine the proper role of high speed shipping a study of the entire door-to-door market over specific routes should be made that includes
   - total elapsed shipping time from factory to consumer
   - total shipping costs
   - integration of high speed ocean shipping with land and air shipping facilities
   - intermodal implications of high speed shipping
   - comparison with alternate shipping methods (air freight, fast rail freight, etc.).
   - price elasticity of the proposed market
2. There is a need for high speed ocean transportation of military cargoes, especially at the beginning of conflicts. The exact nature of this need is being defined. It is anticipated that high speed sealift capability in the United States will depend on the use of commercial ships for military sealift operations (i.e., the Defense Department does not presently plan to build a high speed sealift fleet for its exclusive use).
3. United States shipbuilders substantially lag foreign shipbuilders in efficiency of ship construction. The recent Maritech program and its follow-on, Maritech ASE, are addressing the problems of ship construction. These programs have led to substantial

improvements in U.S. shipbuilding skill and economics. These programs do not specifically address the problems of building high speed ships, an area in which foreign shipbuilders have a lead of nearly two decades.

4. The high operating costs of current high speed cargo ships are directly associated with the cost of fuel they burn. The current design for "Fastship," a semi-planing monohull proposed for operation between Cherbourg and Philadelphia, reportedly requires that it carry 3,000,000 gallons of fuel on a single voyage. There is a need for research into technologies that substantially reduce the fuel required for high speed ship operation. These technologies primarily lie in the area of drag reduction, lightweight materials and improved operating efficiencies of propulsion power plants.
5. Current high speed craft design has concentrated on passenger and car ferries. The designs developed for such markets may require substantial revision to be used as cargo ships, as the loads, method of loading, and load distributions required for cargo are significantly different from those of ferries.
6. Proposed hull form designs for high speed cargo craft are many, and claims for all of them are optimistic. There has been no common hydrodynamic tank testing of competing designs to develop data to help naval architects and marine engineers optimize efficient high speed craft for cargo applications. Hydrodynamic tank testing of competing designs under agreed standard conditions of test are needed to generate the data that is needed to optimize hull form design for specific markets.
7. High speed transit of cargo across large expanses of ocean creates a hazard of collision with slower moving smaller craft, such as fishing boats. It is not clear that human capabilities in detection, command and control of high speed craft will be sufficient to prevent collisions at sea. A method of detecting and avoiding small craft should be developed and its performance verified.
8. High speed ships require port facilities that speed the cargo through the port and onto land-based distribution systems. Ingress and egress from existing ports could delay the ships beyond an economical turnaround time, and the delays in land-based distribution at present port facilities may negate the speed advantage of high speed cargo ships. For these reasons, advanced port facilities and intermodal transportation links must be developed concurrently with high speed ships.
9. The effect of high speed operations on crew fatigue and response has not been adequately investigated in commercial settings, as there are no commercial high speed cargo ships in operation. Studies to define limits on crew performance imposed by long ocean voyages should be designed and carried out.
10. We recommend that a full, focused study of world-wide shipbuilding technology be carried out with a panel of experts. The panel's experts should be chosen from government agencies, industry and academia, and should visit shipyards in Asia, Europe and the United States. The purpose of the panel should be to define areas where U.S. shipyards can be aided by focused research, development and technology programs.

High speed ocean transportation is a multi-faceted challenge, involving interactions between technology, economics and market requirements. A significant advance in ship and port design and construction is desirable. An intermodal approach to the port de-sign is required. These issues must be integrated in a program that seeks to advance high speed sealift capability for commercial and/or military use.

There is no high speed ocean freight operation in the world today ("high speed" is defined as operating continuously at speeds between 40 and 70 knots). Thus there is no experience base for projection of technology needs or the market conditions. This creates a significant opportunity for American shipbuilders and shippers to develop the technology and markets and take the lead in international high speed shipping. Meaningful progress will require substantial investment. Since the U.S. shipbuilding industry has annual sales of only $12 billion, cooperative programs between government and the shipbuilding industry have the potential to accelerate development of high speed sealift technology.

We recommend that the development of high speed cargo vessels for commercial and military use (dual use vessels) be substantially encouraged by the formation of a High Speed Craft Technical Council, operating under the guidance of the federal government, and including representatives from the Department of Defense, the Maritime Administration, commercial shipowners and designers, and academia, to coordinate research and development efforts in this area. We believe that it is important for the United States to lead in the development and deployment of this system of marine transportation.

4.0 Discussion

4.1 The Immediate Need in High Speed Ocean Cargo Transportation

The immediate need in high speed ocean cargo transportation is to **build and operate a high speed cargo ship in commercial service**. Experience in high speed ferry operations has allowed owners to better specify, ship designer to better design, and shipbuilders to better build these craft. However, even with years of experience, there is room for improvement, as last year's *Sleipner* incident clearly shows.[3] Even though much is known by shipowners, designers and builders about high speed vessel design, the lack of high speed cargo ship operating experience is a barrier to ship design. The reason to put a high speed cargo ship in operation as soon as practicable is clear: it is time to test the theories about market response and ship performance. No paper study can substitute for experience; no research and development program can proceed without an implementation test bed.

Good ship design begins with an understanding of service to a specific market. Therefore the first, and most important step, is to define the market to be served in sufficient detail to permit a shipowner to specify the features the ship must have to produce a satisfactory return on his investment. Current studies have dealt only with idealized markets, and thus have not, up to now, provided sufficient detail that a shipowner can specify a ship to serve the market. Shipowners and shippers must be willing to partner in this assessment and to invest in the design and construction of the vessel. Ideally, the initial ship would be used as a test platform, and instrumented to record loads and deflections at designated points in the hull and superstructure.

4.2 Barriers to High Speed Ship Design

Current barriers to improved high speed cargo ship design are summarized in Table 1.

4.2.1 Market Data

The primary barrier to ship design is the lack of specific market data on which to base the ship specifications. A ship carrying perishable cargo such as fruits and vegetables has different requirements than one carrying automobile parts. A thorough marketing analysis of the need for high speed shipping in the Caribbean and on U.S. coastal routes is a high priority. These are the markets most likely to be served first by a high speed carrier. The study should include extensive customer involvement to obtain actual requirements for cargo operations that can be used for completion of conceptual designs. Reviews must be conducted with shippers and other end users of the shipping service to validate the market potential and market support for the service. Critical parameters include data on cargo types/form and annual volumes, as well as peak volumes. Reliability requirements are also important to compare with projected service interruptions because of weather conditions or scheduled ship maintenance. Because high speed shipping costs are heavily dependent on the cost of fuel, the price elasticity of the service must be clearly determined.

An essential aspect of the design process is integrated and coordinated data exchange and transfer between shipowner, naval architect, marine engineer, and shipyard during all phases of design and construction. The ship construction industry is responding to this need with a variety of initiatives. These initiatives should be supported and encouraged. The role of the government as a coordinator of information exchange protocols should be considered.

Table 1. Barriers to Improved High speed Ship Design

Major Barriers to Improved High speed Ship Design	
AREA	BARRIERS
Market Data	Insufficient market data for ship design specifications Integration of shipping/port/intermodal transportation systems Lack of operating data on fast freight ships Insufficient data on factory-to-consumer transportation costs to target logistics bottlenecks and determine true costs.
Hull Dynamics	Lack of experience in high speed cargo vessel performance Lack of comparative hull evaluations in tow tank testing Wake wash control
Seakeeping	Maneuverability in heavy seas Maneuverability during berthing in high winds Crew fatigue prevention
Power/Fuel	High fuel consumption, engine, transmission, and propulsor efficiency
Materials	Design property data base for new material systems Drag reducing anti-fouling coatings
Safety	Collision avoidance systems

Design of a ship is a complex undertaking, often involving dozens of subcontractors. In design of a high speed ship, where some aspects of the design involve application of state-of-the-art technology, the improvement of existing ship design software should be actively supported. In addition, design software that integrates the disparate components and suppliers should receive high priority. Because shipbuilding in the United States is not a large industry, government support may be advisable to give U.S. marine engineers and naval architects a technical advantage over their international rivals.

4.2.2 Hull Form and Dynamics

A barrier identified to the improvement of hull form design is the lack of comparative hydrodynamic tow tank testing data between competing hull designs. Each proponent of a hull design has test data, but there has been little head-to-head comparison in a neutral test tank, where the test parameters are impartially established and all hull designs are tested against them. The optimum hull form may vary with mission; the ideal hull form for a coastal trader may be different from that for a trans-oceanic freighter. In the absence of comparative hull form tow tank information naval architects are hampered in their efforts to alter hull designs to improve performance. At the Carderock conference[4] the Hullforms and Propulsors Working Group concluded that the acceptable hull forms were limited to the following:

- Displacement and semi-planing and slender monohulls
- Displacement and semi-planing multihulls
- Small waterplane twin hull (SWATH), semi-SWATH, and hydrofoil SWATH (HYSWAS)
- Surface Effect Ships (SESs)

They noted that there was no basis on which to select one hull form over another for future development. Since that report was published a set of hull form decision criteria has been published,[5] based on deliberations held at the conference. These are theoretical criteria, and have received limited verification in tank testing. In addition, the authors indicated that other criteria, such as the marriage of the power plant with the hull, may drive hull form design. Other hull forms continue to have their supporters who do not necessarily agree with the results presented in reference 3.[6,7,8,9] It is appropriate to begin comparative testing of hull forms to generate the data required to refine high speed hull form design and marry them to the proper power plant.

Wake wash minimization is a matter of concern in the operation of these vessels. It is likely that high speed ships will slow to speeds under 20 kts in harbors and congested waterways, thus minimizing the effect of wake wash in these areas. In the open sea, however, wake wash may pose a problem for nearby small craft, such as fishing boats. Opposition to high speed cargo ships may be expected by fishing fleets and recreational boaters unless steps are taken to minimize wake wash generation.

4.2.3 Seakeeping

Because of the importance of minimizing drag to achieve reasonable fuel consumption, most high speed ferries are shallow draft vessels. Unfortunately this can make them difficult to control in heavy seas; many high speed ferries have wave height operating restrictions. Such restrictions must be minimized for cargo operations. Because of the limitations of fuel capacity and cost, it is unlikely that high speed ships will necessarily outrun bad weather or go around major storms. The problem of berthing in heavy winds is also important, as quick turnaround in port will be required.

Deeper draft ships, such as some proposed for high speed cargo operations, may be expected to avoid these problems, although as long, slender craft they may encounter other difficulties. However, as deeper draft increases hull resistance and fuel costs, trade-offs may limit the efficacy of relying solely on deep drafts to provide maneuverability.

Seakeeping is often considered to be a minor concern in freight operations as there are no passengers on board. However, the safety and condition of the crew must be considered. There is currently little data on the human response to long periods at the vibrational load that can be expected from high speed cargo vessels. At the lower end of the speed range (around 40 knots) there do not appear to be major problems (evidence for this comes from the trans-Atlantic speed records set by high speed ferries as they are being delivered from the factory). At very high speeds (over 70 kts) in even moderately rough seas, crew fatigue is magnified. In the intermediate range (50 – 70 knots) little has been published on the effect of the ride on crew fatigue and responses, although there is anecdotal evidence that crews on high speed ferries have complained about work-related health problems. In the short term, ship speeds are not expected to reach the high speeds that would require extensive automated ship operation. However, as ship speeds increase, the command and control required may be expected to demand increasing levels of automatic operation. Development work on such systems is therefore a priority, as are studies of the human limitations to high speed marine operating environments.

4.2.4 Power/Fuel Systems

Fuel consumption is the major barrier to economic high speed cargo transportation. Both the cost of the fuel and the volume it occupies on board are significant economic problems. At the present time the volume of fuel and its cost make the profitability of trans-Atlantic or trans-Pacific crossings questionable.

However, for shorter runs, e.g., Caribbean or coastal service, the volumes of fuel required are smaller and profitability should be possible. It is clear that everything possible must be done to increase fuel economy. This includes the development and use of highly efficient marine power plants and powertrains, lightweight materials, and alternate power sources for auxiliary services such as light and electronics power. The ability to disperse these power sources and locate them at their point of use both reduces excess ship weight by eliminating power cables.

Development of efficient marine engines is a challenge for engine manufacturers. At the present time the marine engine industry is facing the necessity of building significantly cleaner-burning engines. In some cases the technology required is pushing the limits of current engine design and manufacturing capability. Other “clean” power sources, such as fuel cells, are not currently at the point where they can be used for primary power plants, and there is no reason to believe that they will develop power levels appropriate for high speed ocean shipping in the next decade. To achieve maximum efficiency, fuel cells must run on pure hydrogen; the infrastructure to supply liquid hydrogen at ports world-wide has not been established, and is not expected to be established in the foreseeable future.

The Propulsion Machinery Technology working group at the Carderock conference estimated the cost of developing a new marine gas turbine power plant at $1 billion and the cost of marinizing an existing advance aircraft engine at $500 million. These figures indicate that a substantial investment in engine technology may be required, which may in itself be a barrier to high speed sealift development. The Carderock conference emphasized that optimum power generation in high speed cargo vessels is a marriage of primary power plant, transmission system, propulsor, and hull form, and strongly recommend that substantial effort be made to study and improve these systems.

At the present time, based on the maturity of the gas turbine engine industry, we project that improvements will be incremental, evolutionary rather than revolutionary. It should be apparent that the gas turbine engine industry has sufficient incentive from its primary customers (airlines and power companies) to make performance improvements without governmental aid. However, efforts to marinize new engines and fit them for ocean-going operations may need to be encouraged by the government, as the total market for marine gas turbine engines does not appear to make such efforts commercially attractive. In addition, programs should be directed toward development of more efficient drives and transmissions, and higher efficiency waterjets.

4.2.5 Materials

The traditional material for use in cargo ships is steel. Aluminum alloys are being used for high speed ferries, and some ferry builders have plans to use similar designs and materials for the first cargo ships. There are concerns about the use of aluminum alloys: they have a lower elastic modulus than steel, and thus deflect more under similar loads. In addition, aluminum alloys have no fatigue limit, meaning that they eventually will fail in fatigue. Steel, however, weighs nearly three times as much as aluminum. Some of the difference in weight can be made up by making steel thinner, but, as steel rusts in marine environments, thinning the steel too much reduces its lifetime and that of the hull or superstructure from which it is made.

The Loads, Materials and High-Strength, Lightweight Structures Working Group at the Carderock meeting estimated that aluminum has a 30% weight advantage over conventional steel, which could grow to 50% with improved joining technology. They cautioned that more knowledge about the fatigue properties of aluminum alloys is necessary. Greater savings were projected with “exotic metals” such as titanium alloys, but there is insufficient data on their properties at present. The same conclusions were drawn for composite structures. These conclusions were similar to our conclusions,[10] although our analysis indicated that glass composites had no advantage over steel in high speed craft.

Because steel and (now) aluminum are the traditional materials for high speed ships, shipbuilders are familiar with how to shape them and join them, designers are familiar with their properties, and owners and crews are familiar with maintenance procedures for them. The use of non-traditional lightweight materials is one way to reduce vessel weight and improve performance. Such materials include resin-matrix composites and lightweight intermetallics, such as titanium aluminides. However, before these materials can be used in ship structures, they must be thoroughly tested, manufacturing procedures must be thoroughly worked through, and maintenance protocols established and verified.

The world-wide market for high speed ships is not large, and it is questionable whether the extensive testing required to place a new material on these vessels is justified economically for a private company. In the absence of standardized test data for all candidate materials, designers are unable to know whether a given material is truly better than the current candidate. It is also quite questionable that these materials would be accepted by the marine industry until and unless they had been used in other applications and found to have clearly defined advantages. In view of their high cost, however, it is unlikely that they will soon find an application (other than aircraft) that would convince naval architects to use them in this application.

The drag associated with high speeds at sea is a barrier to efficient operation of high speed craft. Drag reduction can be active or passive. Passive drag reduction encompasses the use of drag-reducing coatings. Today the entire shipping industry is faced with the necessity to eliminate for environmental reasons the use of tin-containing (TBT) coatings. Alternate coatings to TBT have been developed that have reduced frictional resistance of hulls,[11] although they are more expensive to purchase and apply. Some users have reported improved fuel economy or increased speed as a result of using these coatings.

Much of the government-sponsored research on drag reduction has been focused on drag-reduction techniques for submarines, while private firms have emphasized development of non-TBT coatings and methods of flow control over hull surfaces.[12] So far there have been no breakthroughs in coating technology. As there is no need for quiet operation of cargo ships, active drag-reduction systems, such as bubble generation or electromagnetic field production may have more applicability for these ships than for submarines. The use of electromagnetic fields, is, however, far from being established on more than bench-scale experiments, and there is no assurance that it can be scaled up without using prohibitive amounts of power.[13]

4.2.6 Ship Systems – Collision Avoidance

A possible barrier to the operation of high speed cargo ships is collision avoidance. It is especially important to avoid small boats such as fishing vessels and recreational craft. Many small boats do not carry the sophisticated navigational gear required on larger vessels. One need is for a low-cost position transponder for small craft that signals its presence, position and heading so that the high speed ship can avoid it. A similar, but more difficult problem, is developing a system that can warn of items floating in the open sea, such as logs and containers that have been washed overboard.

4.3 Barriers to High Speed Ship Manufacturing

The barriers that we found to actually building high speed ships were few. They were primarily associated with the use of new materials that might be needed to make the use of these ships commercially attractive. They are summarized in Table 2.

The Shipbuilding/Manufacturing Working Group at the Carderock conference emphasized that there is no barrier today to construction of high speed craft using conventional materials. Some designs might incur extra construction costs over those encountered in conventional cargo ships, but existing construction techniques were considered to be adequate to build the ship designs that existed at that time and that were envisaged for the future. Since that time, the results of the Maritech program have become available, and the Maritech ASE program has taken on other problems in shipbuilding technology that are needed to use conventional materials.

As discussed above, barriers to seamless data transfer within the industry could be a problem to designing and building a high speed ship, especially in advanced designs.

Table 2. Barriers to High speed Ship Manufacturing

Major Barriers to Improved High speed Ship Manufacturing	
AREA	BARRIERS
Data Exchange	Lack of industry standards
Joining	Joint material/process performance data Inspection methods for composite section joints
Shaping	Layup of large composites in advanced systems Inspection systems for large composites
Coating	Whole hull coating systems
Curing	Facilities for curing large hulls
Market	Lack of market definition of essential ship features

If advanced materials are necessary to reduce fuel requirements, the lack of established methods of forming and joining hull components and superstructures using these materials will present a barrier to high speed ship construction. If resin-matrix composites are used for hull forms and/or superstructure, molding capability must be increased in size and control of environmental parameters. Although this may appear to be merely a scaling problem, the sums of money involved in building such a facility make it a major project for most U.S. shipbuilders. A corollary problem is one of inspecting the large molded structures that are produced; in this case techniques developed for inspecting composite aircraft structures may be a useful starting point in technology development.

The lack of established parameters for joining advanced materials together could also be a barrier if these materials are needed, as well as parameters for joining advanced alloys and composites to traditional alloys. In the most advanced ships it is assumed that the lightest weight material that can perform will be used for each ship structural component. Since it is unlikely that these will all be the same material, methods of joining them that do not lead to corrosive failure or joint fatigue failures are needed. Also presenting a barrier are the lack of methods to inspect these joints, and a design data base that relates joint performance to the process parameters used to make the joints.

If coatings are used to reduce drag, methods to apply them over large areas will be necessary. Some coating types, such as compliant coatings, are composites themselves, and methods of economically applying them to hull structures are needed. Lack of coating application techniques for structures of the size of ship hulls present a barrier to their use in high speed ship construction.

Much of the manufacturing technology development that is needed to build high speed craft is the same needed to build conventional ships. This technology is being addressed in the current Maritech ASE programs. As the design and material problems posed by advanced high speed ship design become apparent, it would be advisable to consider establishment of a Maritech-ASE-type program focused on construction problems unique to high speed ships.

5.0 Research and Development Needs for High Speed Cargo Ships

Based on the above analysis of barriers, the research and development needs for high speed ships dedicated to cargo can be defined. They are shown in Tables 3 and 4, and are shown in Figure 1 as a time-phased chart. They have been divided into near, mid- and far-term time frames. An immediate need, to build and deploy a high speed cargo ship in commercial service over a short route, such as Caribbean or coastal routes, is specifically defined.

5.1 Immediate Need

As indicated at the beginning of this report, the immediate need in the area of high speed ocean cargo transportation is to build and operate a cargo ship over a limited route, such as U.S. coastal service or trans-Caribbean services. A number of potential services have been proposed, and periodically such a venture is announced. None, however, have been established. Studies that facilitate an owner's decision to specify a ship capable of operating this type of service are a first step in establishing a design for such a ship. Because the ship is to be designed using current technology, a top speed between 40 and 45 knots is an appropriate goal.

5.1.1 Market Analysis

The market analysis called for in this phase is to be sufficiently tightly focused on the actual service to be supplied that ship specifications can be derived from it. The studies in the public domain that have been carried out to date[2,14,15,16] as well as our own studies (see our reports on Program Elements 2.2.1.1 and 2.2.1.2) are too general to be used to specify (even generally) ship design.

The assessment should begin with the identification of coastal and short sea routes (100 – 1000 nm) that are suitable for high speed ocean cargo transportation. This should include an analysis of alternative transportation routes, including trucking, rail, air, and conventional shipping. The price elasticity of each form of shipping (i.e., the cost/time trade-off) should be clearly defined for each, and the effect of fuel costs should be included. In-depth interviews should be conducted with prospective customers and specific cargoes identified. The market analysis should be concerned with possible routes in and/or between North and Central America. Active partnering of one or more shipowners – including their investment – in this phase of the program is a necessity to assure success of the program.

The first task is to derive market data, including price elasticity, for specific markets of up to 1000 nautical miles. The data should include specific shippers, products, volumes, seasonal variations, etc., to allow a potential shipowner to calculate rates of return on investment. The information should also allow the shipowner to specify ship performance, dimensions, crew facilities, load/unload machinery and equipment, etc., to allow preliminary designs to be prepared. The number of ships that would be required to provide satisfactory service should be determined, keeping in mind that just-in-time delivery of

Table 3. Research and Development Needs for High Speed Ship Design

R&D Needs in High Speed Ship Design by Time Frame					
Time Frame	**Market Economics**	**Powertrain**	**Hull Forms**	**Materials**	**Ship Systems**
Immediate	**Build and operate a high speed cargo ship in a commercial market over a limited shipping distance, such as Caribbean or coastal routes**.				
	Assess coastal or short ocean routes and markets to develop ship specifications.	Concept Design Development (integration of hull, power plant and propulsors)			Analyze High Speed Ship Systems Reliability.
0 -10 Years	**Research and Development Program**				
Near-Term (0– 4 yrs)	Conduct factory to consumer logistics study.	Marinize advanced air-craft engines.	Hydrodynamic tow tank tests.	Establish properties database for advanced composites. Begin development of HSLA steels for marine Applications. Begin development of advanced drag-reduction coatings.	Assess Collision avoidance Systems.
Mid-Term (4 – 7 yrs)	Develpo market data for 1000 – 4000 nm shipping.	Improve efficiency of large waterjets.	Develop active systems to minimize drag. Refine and optimize hull form design.	Establish properties database for advanced intermetallics. Continue HSLA and advanced coating development.	Develop low-cost position indicating system for small craft.
Far-Term (7 – 12 yrs)	Develop market data for 4000 – 8000 nm shipping	Investigate feasibility of nuclear power as primary power source for high speed ships.	Develop automatic guidance control for high speed cargo Ships.	Complete HSLA and advanced coating development.	Assess distributed power systems and fuel cells for local power needs.

components to factories is usually done in one to three hour time blocks, daily, with provision for weekend service. The service should be differentiated by products so that ship design can be optimized for specific products and markets.

The analysis should consider the requirements for cargo transportation time scheduling, port conditions and operating charges (and any surcharges that might be required of high speed ships), and possible adverse weather conditions at the port that could be expected to disrupt operations. Intermodal cargo transfers at the port should also be evaluated to assure that the advantages of high speed shipping are not lost in land-based delays. The effect of fuel price increases on ship operational profitability must be included in the analysis. The studies should permit a shipowner to proceed with the acquisition of a ship that can serve the market profitably.

An analysis of the effect of weather in the area of the proposed routes on ship performance and reliability is also recommended. The effect of weather interruptions on the capability of the ship to reliably meet scheduled sailing dates should be considered. An estimate of the maintainability and availability of the service based on ship systems and equipment maintenance requirements is also necessary.

5.1.2 Ship Design (Powertrain, Hull Form, Materials)

The design of the ship should be carried out with the object of building a ship that implements the best in existing technology. The design should be carried to the point that it is possible to estimate speed, payload and fuel consumption. Cargo handling systems should be defined, and an estimate made of ship acquisition and operating costs.

The design process should integrate the hull form, the primary power source, power transmission system, and propulsors to achieve the most efficient ship within the current state-of-the-art. Proven technology and materials should be used. While the ship must fulfill a commercial role (it must be profitable to its owner) it is also a test bed for current concepts in fast seaborne cargo transportation. The technical purpose of building the ship is to gain operational experience, to learn how repeated operation under the loading and scheduling requirements of a strictly cargo high speed ship affects material performance, powertrain components and other ship systems.

5.1.3 Ship System Reliability

Because the ship is to be designed using current technology, it should be possible to analyze the failure probabilities of each of the ship components, and thereby to arrive at an estimate of the performance reliability of the ship design. This analysis should indicate areas where potential problems exist, allowing consideration of other designs or components. This analysis should also guide the assignment of research, development and engineering priorities as the effort to establish the enabling technology for high speed ships.

5.2 Research Program

We recommend that a program be carried out to develop basic technology to permit a second and third generation of ships to be deployed within eight to ten years of the building of the first generation ships. Each generation of ships should have lower operating costs, longer range, and higher payloads that the previous one. The specific projects recommended, by time frame, are discussed briefly below. A timeline is included in Figure 1.

5.2.1 Ship Design

5.2.1.1 Near-Term *("Near-Term"is defined as the period 2001 - 2005)*

5.2.1.1.1 Market Economics

A study of factory-to-consumer logistics should be made to permit intelligent intermodal transportation decisions to be made. These studies should be port- and cargo-specific, and of such detail as to allow port and harbor authorities to use them to plan improvements in intermodal facilities. More than one port should be considered, and the effect of the use of alternate ports should be a part of the ship market study. The effect on service efficiency of calling on multiple ports in a single run should be considered. While it is recommended that the initial study concentrate on the high speed service to be offered as a result of the ship designed as recommended above, the study should include major port facilities on the North Atlantic route and U.S. coastal routes. Alternative forms of transportation to and from the ports from the factory and to the consumer should be examined, including highway, rail, air and the use of the U.S. inland waterways to transport goods from ocean ports to inland destinations. The analysis should also evaluate environmental loading (especially greenhouse gas generation) per ton of cargo moved by each at each stage in the transportation chain.

5.2.1.1.2 Powertrain

It is questionable that the cost of marinizing an advanced aircraft gas turbine engine, such as the GE 90, is justified by the total market for such an engine. However, these advanced engines offer power in the range that will be required for trans-oceanic cargo ships. It is appropriate to study the technical problems involved and explore technical development programs that have the potential to lower these costs. In the short term a team consisting of gas turbine manufacturers, DoD and DoT representatives, and shipowners should be formed to define technical and economic requirements for these engines, and to define a technical program to facilitate marinization of these engines.

Of particular importance are those engine enhancements required for operation in marine environments. The conversion of an aero or land-based engine to a marine engine, known as "marinizing" involves adjustment to materials, control systems, load distribution and other items. Marinization often takes place after the engine has been adapted for land-based power applications. The steps in the process of marinization should be studied and a method of optimizing the procedure designed, with the object of reducing its time and cost.

It is clear that improvements in efficiency in the power transmission train will also be necessary to optimize performance of high speed cargo ships. It is anticipated that there are sufficient economic incentives for industry to develop those improvements on their own. However, the project team should remain alert to encourage promising new technology that would substantially improve high speed ship powertrain performance.

5.2.1.1.3 Hull Forms

A near-term objective in hull form development is to submit the leading contenders for high speed cargo hull forms to tow tank tests. This would allow prospective shipowners to determine which hull form is best suited to the mission intended by the owner. It would also provide naval architects with data to be used to improve and optimize hull form design. The tests should be carried out at a neutral site, such as the David Taylor Model Basin, and a panel made of independent naval architects should define the tests and measurements to be made, in consultation with prospective shipowners and the proonents of hulls to be tested.

5.2.1.1.4 Materials

Because of the relatively small market for marine materials (in contrast with markets for automotive materials) there is a need for increased attention to the unique materials problems posed by high speed cargo vessels. Three areas have been singled out for attention. Research in these areas should be regarded as long-term in nature, and for this reason should begin at the earliest possible time.

The first area, and the one with the best chance for early implementation, is the development of a design database for advanced composite materials. Property tests must include (in addition to the standard static tensile tests) fatigue, fracture toughness, and impact tests in marine environments, using sample sizes large enough to give statistical comfort to designers. The decision as to which tests are appropriate needs to be made by industry personnel, including representatives of classification societies. Because of concerns about fire safety, the composites selected must be able to meet classification society safety of life at sea (SOLAS) requirements for fire resistance.

The second area, and one that will undoubtedly require a multi-year, multi-task project, is to develop corrosion resistant high strength low alloy (HSLA) steels specifically for marine environments. We anticipate that the material of choice for hulls will continue to be steel, as the lower elastic modulus of aluminum and the fact that it lacks an endurance limit implies that aluminum ships would not have as long a life as a steel ship. The Japanese government is currently sponsoring similar research;[17] they expect that successful development of this material will lead to increased Japanese market share in both steel production and shipbuilding. Similar efforts should be made in the United States. Techniques have been designed to substantially reduce the time required for alloy development;[18] these should be explored to produce a corrosion-resistant steel having opment;[18] these should be explored to produce a corrosion-resistant steel having such high strength that it can be used in section thicknesses half that of aluminum to produce weight savings in hulls and other structural members of the ship.

The third area where advanced research should be encouraged is the development of drag-reducing hull coatings. A number of programs are under way; these should be supported, and preliminary research into other promising coating systems begun. Efforts should be made to explore compliant and self-healing coatings through open competition from industry and academia.

5.2.1.1.5 Ship Systems

Collision avoidance is a major concern in the operation of high speed ships. In the operation of fast ferries today, it is customary for one officer on the bridge to operate the craft, while the other is responsible for watching for boats or other objects in the ship's path. While fast ferries often operate at speed in more congested waterways than the open ocean, thereby requiring a higher degree of crew vigilance, high speed cargo vessels transiting the open ocean are at risk from fishing boats and occasional pleasure craft that are not familiar with the speed at which these ships move.

In the short term there is a need to assess the current state-of-the-art in collision avoidance systems, and determine the applicability of such systems to high speed marine navigation. This study should define gaps in the technology for detecting hazardous flotsam (including objects that would not damage the hull, but could disrupt operation of waterjets or other propulors). Gaps in detection technology should be defined, and promising areas for further investigation identified.

5.2.1.2 Mid-Term ("Mid-Term" is defined as the period 2005 – 2008)

Mid-term research, development and engineering tasks will depend on the results of the short-term studies. In addition, we recommend that a number of activities take place in this time frame.

5.2.1.2.1 Market Economics

By 2005, it is expected that results of the Fastship Atlantic business venture will be known, and it will be possible to determine whether there is a market for a faster, or more reliable, or lower cost service on this route. Also, high speed cargo ship technology should have advanced to the state such that performance limitations perceived today may no longer be valid. The market survey (dealing with routes of 1000 – 4000 nm) should consider alternate ports in Europe other than Cherbourg (the Fastship Atlantic port). Thus at some point during this time period, it should be appropriate to perform a detailed market analysis similar to the short-range study performed in the near term. Again, one purpose of this market study is to define the specification for the proposed ship.

5.2.1.2.2 Power Plants

The major thrust in mid-term development should be improvements in the efficiency of large waterjets or other propulsor systems (such as wave-piercing propellers) in use in high speed cargo ships. The first very large waterjets will go into operation on Fastship Atlantic's fleet, and evaluations of their performance should permit definition of a program to improve them, as well to improve integration of hull form, power plant, power transmission and propulsor system in subsequent ships.

5.2.1.2.3 Hull Forms

There have been a number of radically new approaches to drag reduction, as mentioned above, that involve hull form dynamics and the use of active systems to reduce drag. It is recommended that during this period these systems be reviewed and support given to efforts to apply them to large hulls and hull forms used in high speed ocean shipping.

Based on the results of the tow tank tests, efforts in the mid-term should be focused on refining the designs of high speed hulls, with an emphasis on those features that make the hulls attractive for long-range (trans-Atlantic) service, and reduce wake wash.

5.2.1.2.4 Materials

Work should begin to develop design data bases for advanced intermetallics, which promise advantages in performance over existing traditional materials. The materials selected for data base work would be those that showed economic promise based on the results of the alternate material design exercise recommended for the near-term. A team of classification society representatives, the U.S. Coast Guard, naval architects, and materials engineers should select the tests and load cycles. If near-term projects are promising, work should continue on development of drag-reducing coatings and high strength low alloy corrosion-resistant steels.

5.2.1.2.5 Ship Systems

Collision avoidance is not solely the responsibility of the high speed cargo ship. Small craft owners share this responsibility. One solution is to develop a very low-cost transponder that can broadcast the position of the small craft, thereby allowing it to be seen by high speed ship radar. Such a low-cost transponder is currently under development for small aircraft operating in Alaska and the extension of this technology to small boats and pleasure craft should be developed. The device should be compatible with standard navigational equipment in use on high speed ships.

5.2.1.3 Far-Term ("Far-Term" is defined as the period between 2008 and 2013)

The far-term program assumes that there will be progress in the short and mid-term projects that makes it possible to extend high speed shipping to Pacific Ocean markets. In the far term, we expect to see ships designed using the lightweight advanced materials that have been characterized in the short and intermediate term programs.

5.2.1.3.1 Market Economics

We recommend that marketing studies should be extended to Far East markets (4000 – 8000 nm), as ship technology is not sufficiently advanced today to provide data that would be meaningful when the technology is fully developed. As in the previous studies, these should be in sufficient detail to permit a fleet of ships to be specified. As it is envisioned that trans-Atlantic services will be well-developed at this time, the study should reflect the experience of existing high speed cargo operators.

5.2.1.3.2 Power Plants

The use of nuclear power must be recognized as a potential solution to the problem of power and fuel consumption in the long term. Power requirements for high speed ships, especially those traveling at speeds greater than 50 kt, are currently so high as to make the use of fossil fuels un-economical, and there is no current evidence that advances in fossil fuel power plants, materials, hull forms or drag reduction technology will substantially alter this in the next decade. Up to now, it has been assumed that nuclear power is a forbidden solution, because of strong opposition from environmental and other anti-nuclear groups around the world. As the problem of global warming becomes more acute (and in many nations, especially in Europe and Japan, there is rapidly increasing concern over the production of greenhouse gases in the production of energy) nuclear power is increasingly attractive. [19]

If a nuclear-powered ship were built, it is likely that the ship would also be equipped with fossil fuel auxiliary and emergency power, as is the case in nuclear power plants. In such a case, it would be possible for a boat to meet the nuclear ship outside of national limits, and remove the nuclear fuel from the ship. The ship could then proceed to port under diesel or turbine power. After the ship had been loaded and serviced in port, it could leave, pick up the nuclear fuel, and then proceed under nuclear power to the next port where the procedure could be repeated. In this way the advantages of very fast ocean transportation could be obtained without the necessity for nuclear fuel to actually be present at any time in a restricted port area.

In light of what appears to be a changing appreciation of nuclear power, the application of nuclear power plants for marine applications should be observed carefully over the next ten years. If it appears that nuclear power does indeed offer an acceptable solution to reaching the high speeds that may be desired, the industry should be prepared to implement it.

5.2.1.3.3 Hull Forms

As the speed of the ship and the distance between ports increase (i.e., as 50 to 70 kt ships engage in trans-Atlantic and trans-Pacific trade) the ability of the crew to react quickly enough to emergency situations to avoid collisions or other problems may become a serious problem. In addition, at high speeds the motion and vibration of the ship is expected to have an adverse effect on crew performance. At the present time, there does not appear to be a satisfactory way to damp vibrations and accelerations so that crew members are not affected during the voyage. This could be a significant barrier to very high speed shipping, and should receive increased attention. The technology should take advantage of active control of hull surfaces and control surfaces to adjust the performance of the ship to produce the most efficient way through the water, while avoiding hazards and minimizing transit times between ports. This is an approach that requires extensive integration of hull forms, propulsion systems, and control systems, both in a static sense (the design of the ship) and in as active real-time control and dynamic response.

The development of completely automated ship control systems, designed expressly for high speed ships, should be a high priority of this program. While we do not contemplate the operation of crew-less vessels, a goal of the development program should be to make such operation feasible.

5.2.1.3.4 Materials

Research to develop better coatings and corrosion-resistant HSLA steels should be completed in the far-term, and use of these materials should be implemented in high speed craft during this time period.

5.2.1.3.5 Ship Systems

In the far-term, it may be possible to use non-traditional power systems in distributed power applications. These systems, such as fuel cells, could be used to power local power needs like lighting, galley power, bow and hull thrusters (if needed) and computers. Thus efforts should be directed marinizing these power sources, and packaging them and their fuel supplies on the ship.

5.2.2 High Speed Ship Construction

Our review of the Maritech ASE program led us to the conclusion that this program is adequately meeting the needs of shipbuilders for conventional ships. This program should be augmented to provide a mechanism for encouraging the development of manufacturing technology that will be different for advanced high speed ships. A list of potential projects is presented in Table 4.

5.2.2.1 Near-Term:

5.2.2.1.1 Simulation Systems

It is assumed that development of an industry-wide data exchange system will take place naturally, through industry efforts encouraged by MaritechASE programs. In the same way, we expect that computer-aided design aids will continue to be developed by the private sector. However, we recommend that both DoD and DoT monitor the development of advanced hull design modeling developments, and encourage advancements and implementation of the most advanced design tools by industry. A competitive program to develop modeling tools that are focused on high speed cargo hulls may be justified.

5.2.2.1.2 Materials Processing

Because of the limited market for processing methods that address the large structures required by cargo ships, the major area where manufacturing development is needed must address the problems that manufacturing ship structures pose.

The first area is that of coating application systems for large complex hull structures. Drag reducing anti-fouling coating systems will initially be developed for steel, and may be extended to aluminum and perhaps even advanced materials. The coating applications systems should be developed concurrently. Coating system development must consider not only methods of attaching firmly adherent coatings, but environmental problems associated with the method used to apply the coatings, as surface treatment offers a major opportunity for environmentally benign manufacturing methods.

A need in the manufacture of large composite materials is development of methods of curing large structures. The limitations on the length of hulls that may be manufactured today in composite materials are imposed by limitations in curing facilities and methods. An *in-situ* method of curing composite resins would be ideal; until such a method is developed, larger curing facilities, or a step-wise incremental curing method for hull forms is needed.

A second area of need for composite materials is development of methods to join these materials to themselves and to each other. A good place to start is the technology developed for aircraft. However, the loads and operating environments of marine structures are significantly different than those of aircraft. This implies that the joints used to attach them will have to satisfy more stringent requirements. In the short term, a major effort to upgrade aircraft composite joining techniques should be launched.

5.2.2.1.3 Data Exchange

The development of industry-wide data exchange protocols is a high priority, as the shipbuilding industry is highly fragmented between naval architects, marine engineers, shipyards, subcontractors, and classification societies. Rapid and efficient data exchange is needed to accelerate delivery times. A number of Maritech and Maritech ASE programs are focused on rapid data exchange. These programs should be encouraged, and extended to subcontractors and equipment vendors that are not normally involved in conventional shipbuilding but whose products impact the high speed market.

Table 4. Research and Development Needs in High speed Ship Manufacturing
R&D Needs in Manufacturing Technology by Time Frame

Time Frame	Simulation Systems	Materials Processing	Data Exchange
Near-term (0 – 4 yrs)	Continue to upgrade existing design and simulation systems	Develop coating systems for very large structures. Develop curing systems for large composite hull forms Develop methods of joining composite hull forms to each other	Develop industry-wide data exchange protocols
Mid-Term (4 – 7 yrs)	Extend design capability to give ship owners interactive design input to naval architects	Develop inspection systems for large laminated composite hull sections Develop automated inspection systems for friction stir welds Develop forming methods for large (~300 m) complex composite hull forms	Extend data exchange to sub-contractors (i.e., establish business-to-business system for U.S. shipbuilding)
Far-Term (7-12 yrs)	Develop design systems that integrate business models with ship design requirements	Develop methods of joining composites to advanced materials Develop on-board joint and structural member inspection methods	(No far-term data exchange projects are currently envisaged)

5.2.2.2 Mid-Term:

Mid-and far-term activities are extensions of near-term projects. To a large extent, these will depend on the manufacturing and materials processing problems that result for specific ship designs, hull forms, power plants, etc.

5.2.2.2.1 Simulation Systems

The goal of simulation systems in the mid-term should be to give shipowners the ability to interactively influence the design of the ships during design and build. Since changes introduced while the ship is under construction often increase the cost of the ship this capability should include a method of rapidly estimating the cost of the design change at the time it is made.

5.2.2.2.2 Materials Processing

The first major need is the development of techniques to inspect joints in composite materials and between composites and other materials used in advanced ship structures. Although a number of methods have been developed and are in use on aircraft structures, the large size and specific shapes of ship hulls will require modification of existing equipment and methods. One problem that is anticipated is that composite hulls are expected to be thicker than control and containment surfaces on aircraft, and thus require more sensitive sensing equipment and better signal resolution than inspection equipment used for aircraft structures.

Another need will be methods for automatically inspecting friction stir welds in aluminum hulls and superstructure. Friction stir welding is still under development, and appears to offer advantages for aluminum structures, such as hulls and superstructures. Defects in friction stir welds are different from those found in conventional fusion welds, and methods of examining welds for unbonded areas and microstructural anomalies should be developed to permit shipyards to apply this new joining technology with minimum requirements for manpower and training.

The requirement that hull forms and propulsion units be integrated for maximum efficiency may require that hull forms be of unusually complex shape. If composites are to be used to lighten the weight of the ship, methods must be found to shape them into the forms required at the lengths (up to 300 m) that are needed to provide sufficient space for cargo. Emphasis should be put on incremental forming methods that minimize the use of energy to minimize costs.

5.2.2.2.3 Data Exchange

Data exchange and modeling activities will be continued by the private sector. These activities should be monitored to assure that the best practice is being implemented in the shipbuilding industry. Data exchange should be expanded during this period to include component suppliers and subcontractors. The use of the internet in business-to-business mode should be encouraged to lower ship acquisition costs.

5.2.2.3 Far-Term

5.2.2.3.1 Simulation Systems

A far-term project is the application of artificial intelligence and expert systems to integrate ship design with business models. Development of automatic methods of assessing whether a given ship design will meet the financial performance envelope desired by its owners should be encouraged to allow owners and ship designers (naval architects and marine engineers) to specify ship characteristics and refine ship designs before ships are constructed.

5.2.2.3.2 Materials Processing

The first requirement in the far-term will be to perfect methods of joining composite materials to each other and to metallic and advanced materials (e.g., intermetallics, tailored alloys). Joining methods and non-destructive evaluation methods of the joints produced should proceed concurrently.

Maintenance protocols, and procedures for inspecting ships in service must also be developed. High speed ships are expected to be subjected to loading profiles much more severe than those experienced by conventional cargo ships, and methods of assuring their integrity at sea (i.e., on-board inspection systems, or smart materials that indicate when defects approach critical size) will be needed to keep them productive. These systems and materials will need to be developed, tested and implemented on high speed fleets. Protocols for regular portside inspections for those maintenance areas where inspection while under way is not feasible should be developed, and the equipment necessary specified.

5.2.2.3.3 Data Exchange

By the year 2008 we anticipate that automated data exchange and widespread use of the internet will stimulate the private sector to refine existing data exchange systems without the need of government encouragement.

5.3 Ergonomics and Crew Response Studies

Our study of barriers to high speed sealift technology raised concerns about the effects of high speed ship motions on crew health and response. We were unable to find definitive information on the extent of the potential problem, but anecdotal evidence, from mariners and others who have had experience on high speed craft, indicated to us that this is an area where research is needed. We are not able to define the nature of this research (it is beyond our area of training and expertise), but we have included it on the road map, as it is clearly an area where more work is needed. We recommend that occupational health experts be called upon to recommend research in this area.

6.0 Summary

The recommendations made in this report can be used to guide development of enabling technology to allow U.S. shipbuilders to compete successfully in the high speed ocean-borne cargo transportation market. This market will grow, and provide an opportunity for U.S. shipbuilders to regain a significant portion of world-wide shipbuilding business. The development of ship designs that meet the needs of the market must be accompanied by the development of manufacturing techniques that allow them to be built at competitive prices in the United States.

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