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Projected Ship Types to the Year 2000

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ABSTRACT

In defining the direction that ship structural research should be taking, it is important that we be aware of the types of ships that will be required in the future, and the structural challenges that these ships will present, lest we concentrate our efforts on the wrong problems. The marine vehicles of the future will present many structural challenges by virtue of requirements for new services, missions and trades heretofore unencountered. This paper presents a view of the ship types that will be required in the year 2000, with the objective being to determine the requirements for advanced structural research, and to provide a basis for developing technology beneficial to the marine industry and the nation as a whole.

INTRODUCTION

This paper makes use of the science of technological forecasting, which has made dramatic advances over the past decade. Through use of such formal quantitative assessment tools as factor analysis, trend impact analysis, input/output analysis, cross-support matricies, and model split models, one attempting to forecast the future can significantly improve upon an expert's "educated-guess" by bringing to bear on a problem many more relevant factors than can be qualitatively considered at one time. It should be made clear that in modern technological forecasting the key element is still expert judgement, but the effect of this judgement is greatly magnified by analytical techniques. The results of this paper are based upon the findings of several recent technological forecasts, all of which are mentioned in the references.

This paper covers two categories of marine vehicles: commercial ships, and offshore structures. The presentation may appear to be biased in favor of innovative ship types. This emphasis is intentional, but not because it is believed that innovative ships will predominate at the end of the century. To the contrary, the vast majority of marine vehicles in the year 2000 will probably be very similar to those existing today. However, innovative ships will be required for commercial, military, ecological, and resource needs, and even through their numbers may not be great, we must identify today the technical barriers that must be overcome to bring them to fruition, if we are to be able to satisfy the need when it arises.

COMMERCIAL SHIPS

Total U.S. waterborne commerce, now at the level of 1.5 billion tons per year, will grow to an annual level of 3.5 billion tons in the year 2000[1]. This is a tremendous increase, and its impact upon commercial shipping will be very significant. Commercial ships have lately been divided into four service categories, distinguished by the character of goods and the resulting services they require. These service categories are: bulk shipping, neobulk shipping, general shipping, and express shipping.

Bulk Shipping—This category is characterized by large cargo lot size and low cargo value. Delivery timing is generally not critical, and service speeds are low; freight rates are low, so that economies of scale are important. Bulk cargo vessels tend to be large and slow, with a high proportion of the shipping system cost in ship acquisition. Typical bulk cargoes are crude oil, iron ore, coal, grain, and phosphates.

Liquid Bulk—The most common liquid bulk carrier is the oil tanker, with over three thousand of these ships, totalling 250 million deadweight tons, sailing the oceans of the world. At present there is a large worldwide oversupply of oil tankers, with estimate of the surplus ranging from 25 to 95 million deadweight tons. This situation has been caused by the severe dislocations in the world oil markets. During the late 1960's oil consumption grew rapidly, and large tankers were being built at an accelerated rate to fulfill the transportation demand. However, the Arab oil embargo of late 1973 changed the picture overnight. After rising rapidly for a decade, worldwide oil consumption actually declined in 1974. The result has been a glut of tanker tonnage.

Uncertainty in the worldwide oil markets still exists. Although nearly two years have passed since the Arab boycott, government policies on the development of domestic energy resources, environmental measures, taxation, and imports are still being formulated. Some things, however, are clear, such as a drop in oil consumption forced by higher prices. Tetra Tech[2], for example, predicts a drop in the annual rate of growth in oil demand to 3.5% up to 1985, and to 1.3% from 1985 to 2000. This will bring the supply and demand of oil tankers back into balance in 1980[3]. After 1980, though, demand for new tankers should grow, but at only half the rate of growth in oil consumption. This is because the reopened Suez Canal, coupled with increasing production from North Sea and Arctic oil fields, will result in shorter transportation routes than those now experienced.

Innovations in liquid bulk carriers will come in four areas: larger size, arctic operations, cryogenics, and special carriers.

First, the size of the average tanker on order has grown almost eight-fold in twenty-five years, from 16,500 DWT in 1950, to 130,000 DWT in 1975. This upward trend should continue, although at a reduced rate, because the economies of scale are unmistakable, a 250,000 DWT ship being about 5% more efficient than a 100,000 DWT ship. One of the primary reasons for the greater efficiency of larger ships is that it takes no more men to operate a large ship than a small one. Consequently, tanker crew size per thousand deadweight tons has been reduced from 3 men in 1950 to less than 0.1 today (see Figure 1). Figure 2, which is a projection of the

FIGURE 1

CREW SIZE

(TANKERS)

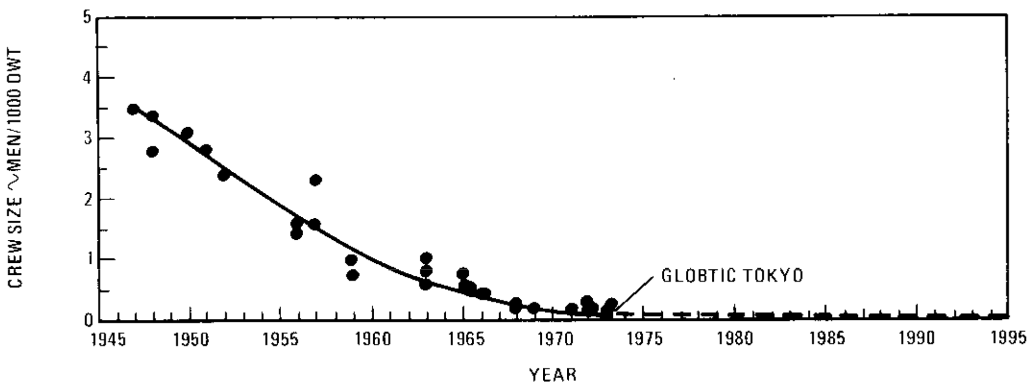
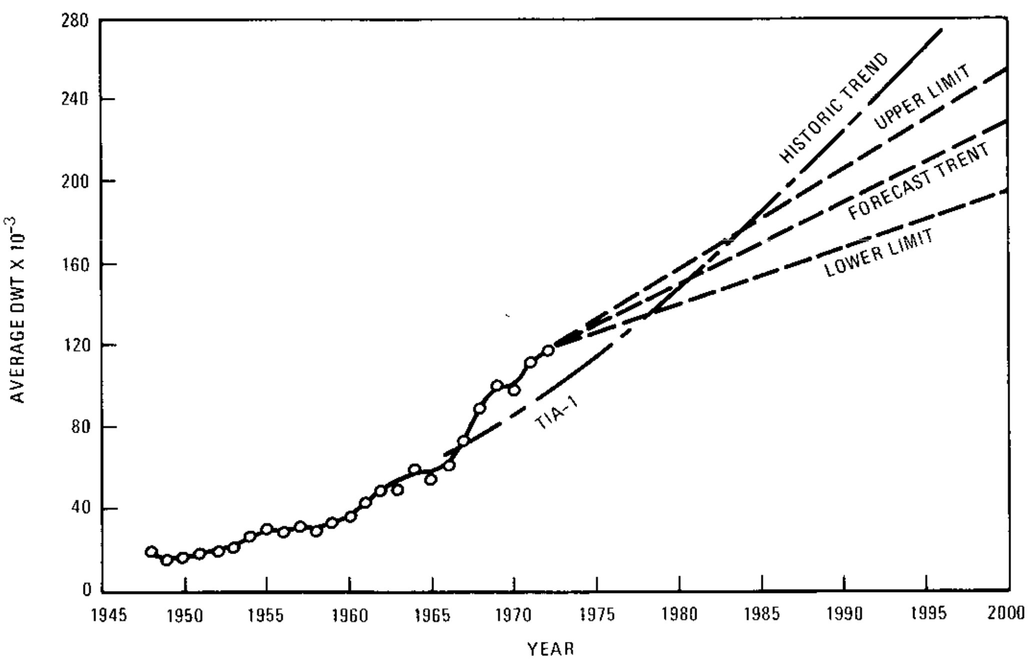


FIGURE 2

AVERAGE TANKER DEADWEIGHT ON ORDER



size of the average tanker on order, shows this "average" tanker to be about 230,000 DWT in the year 2000[1]. Actually, this "average" will be composed of two tanker sizes which should predominate at the end of the century. The first will be the feeder tanker of 60,000 to 70,000 DWT and a draft under 40 feet. This ship, which will be utilized on short voyages, will be able to transit the Suez Canal, have maximum access to coastal refineries and tank farms, and will take advantage of the segregated clean ballast regulations of the Intergovernmental Maritime Consultive Organization (IMCO), which applies to ships over 70,000 DWT. The other predominant tanker size will be in the 350 to 400,000 DWT range, which will become the world's workhouse on long ocean voyages[4]. Considering maximum size, United Aircraft Research Labs (UARL) predicts tankers of 1.6 million DWT by 2000[1], while the Aerospace Corp. predicts a maximum size of 1.5 million DWT[15]. This will present unique structural challenges in the areas of design and fabrication.

Exploitation of Arctic and Antarctic oil reserves will also cause major changes in tanker design. The north slope of Alaska, for example, is expected to yield five million barrels of oil per day towards the end of the century[2]. Most of this oil will be carried by pipeline to Valdez, where conventional tankers will carry it to West Coast ports. However, even larger oil reserves are located further north, beneath Canadian islands not accessable to pipelines. Large ice-breaking tankers will be required to move this oil to market. The historic voyage of the S.S. Manhattan paved the way for such developments. Later tankers, designed from the ground-up as ice-breakers, and utilizing nuclear propulsion as well as the latest ice-breaking technology, should make these northern voyages in routine fashion[5]. Also, an even more challenging application of today's technology, the nuclear powered submarine tanker, whose operation is unaffected by ice and weather conditions, could be in common use within twenty-five years. The concept may appear radical, but the technology base exists, the oil exists, and the entire operation can be very profitable, as demonstrated by the 18 to 32% return on investment predicted by Newport News Shipbuilding[6].

The bulk transportation of cryogenic liquids will present the third challenge to structural designers and fabricators. Liquefied propane has now been successfully transported for a decade, and liquefied natural gas (LNG) carriers are now rapidly coming on-line, with sixteen now under construction, and applications for eleven additional ones now pending in MarAd. While 125,000 cubic meters is the common size of today's LNG carrier, the economies of scale should catch up with these vessels as they have with all others. Ships three times this size should be commonplace in twenty-five years[1]. Safety is a crucial issue with these ships with the largest problem resting upon the shoulders of the structural designer and fabricator. The problem will become even more acute as even colder products, such as liquid hydrogen are transported.

Advances in specialized liquid bulk carriers will also be innovative in nature. The products tanker, heretofore a ship small in size and numbers, should grow in size and in quantity because of the growing trend of oil exporters to also become oil refiners. The chemical tanker should also increase in quantity due to increasing industrialization of developing nations. Certain commodities which are now carried in pressure vessels will become candidates for low temperature containment. Vinyl chloride, for example, can be transported at atmospheric pressure at -14°C instead of in pressure vessels at 89 psig. Chlorine, now transported in pressure vessels designed for 300 psi, can be carried at a pressure of one atmosphere and a cargo temperature of -36°C[7]. Because of the hazardous nature of many specialized liquid products, structural advances will be required in designs for increased collision protection, and in development of corrosion resistant low-temperature containment materials.

Dry Bulk—The major dry bulk commodities in the year 2000 will be grains, coal, iron ore, bauxite/alumina, and phosphate rock, in that order, and will total nearly 300 million long tons [1] (see Figure 3). The economics of scale are more prevalent in dry bulk carriers than they are in tankers, causing the growth rate of bulk carriers to be even more spectacular than that of tankers. The size of the average dry bulk carrier on order has grown tenfold since 1950. Although dry bulk carriers are limited by available port facilities, it is expected that significant advances will be made in this area, such that the average bulk carrier on order will grow to 125,000 DWT in 2000, with a possible high value of 147,000 and a possible low value of 108,000 DWT (see Figure 4).

FIGURE 3

DRY BULK CARGO TONNAGE

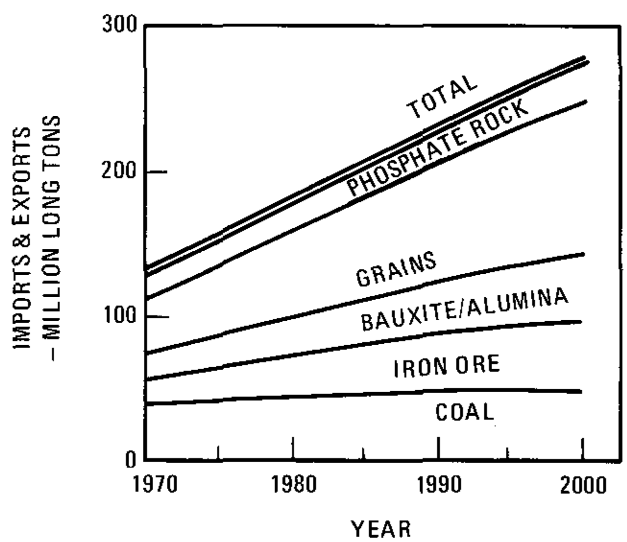
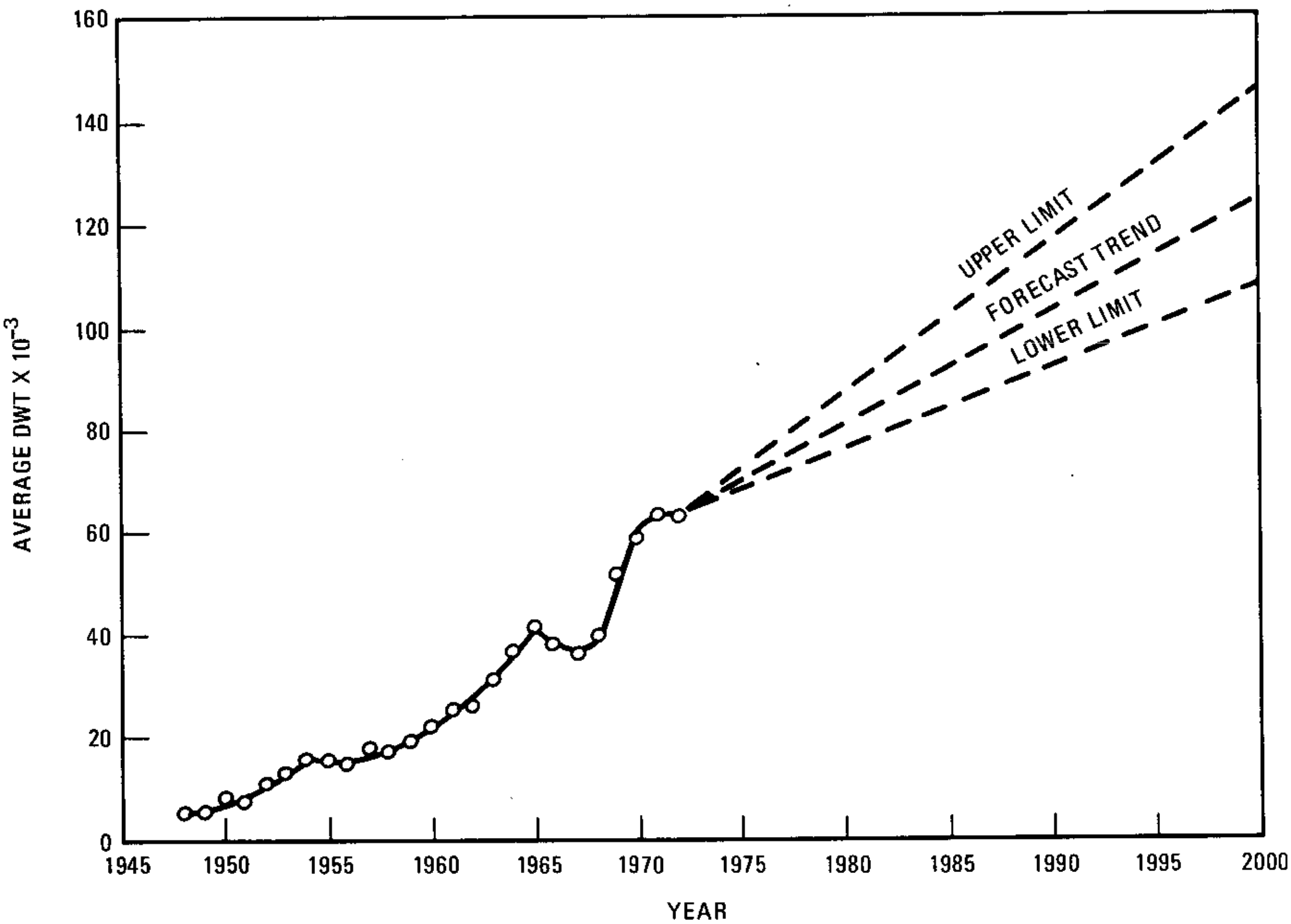


FIGURE 4

AVERAGE DRY BULK CARRIER DEADWEIGHT ON ORDER



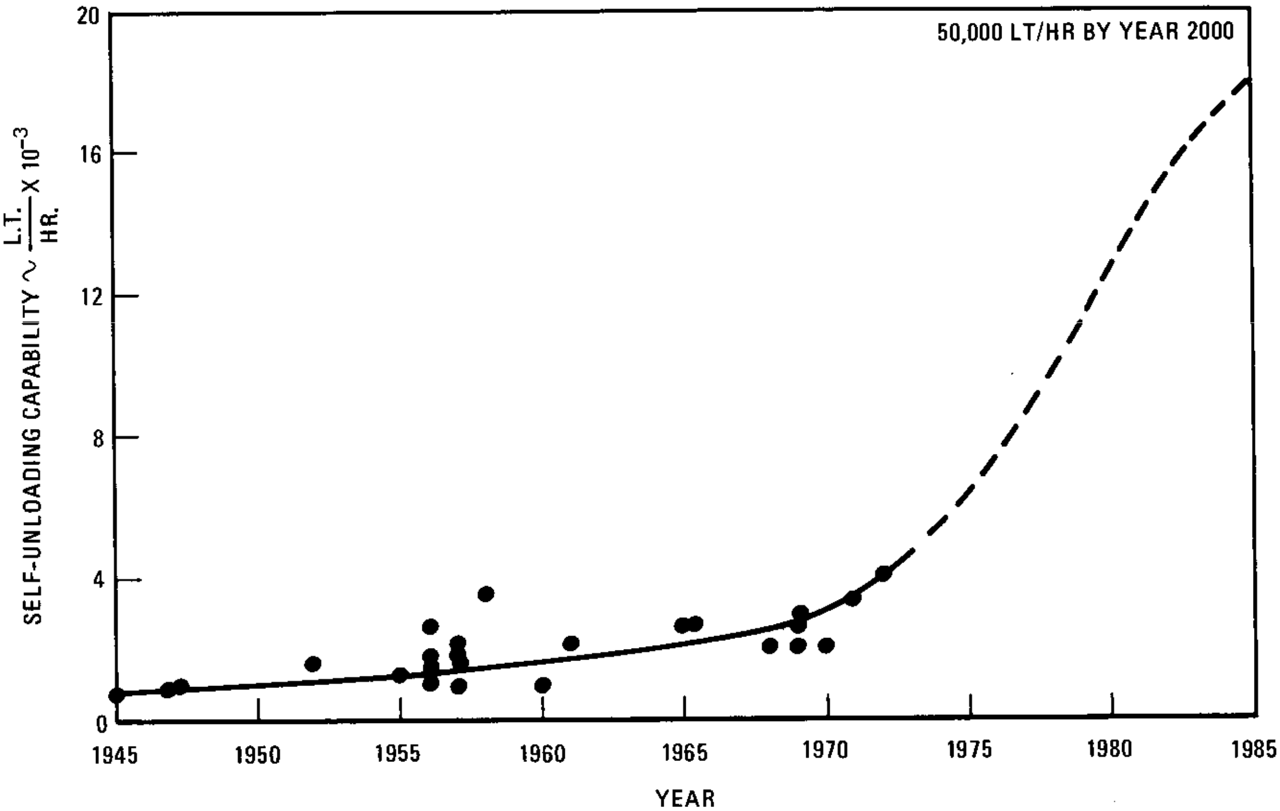
Innovations in dry bulk carriers will come principally in three areas: increased productivity, unusual ship proportions, and change of form of product. Regarding productivity, increased vessel size has resulted in a considerable emphasis on cargo loading and unloading. The application of shipboard unloading gear to oceangoing dry bulk carriers has heretofore been slight since bulk discharge ports have up to now been fitted with shoreside discharge gear. Shoreside gear, however, has not kept pace with increases in ship capacity, making for long pier side delays for the large dry bulk ships. Owners can be expected to alleviate this problem by giving their ships a self-unloading capability. This trend will be especially evident on ore carriers, which are deadweight limited, meaning the volume required by the unloading gear will result in little loss of carrying capacity. It is possible that by the year 2000, 500,000 DWT ore carriers will be fitted with self-unloading gear with 50,000 ton per hour capacities that can discharge the vessels in ten hours (see Figure 5).

In the area of ship proportions, much work has been done of late in developing shallow draft technology for large ships. The large shallow draft bulk carrier offers the economic advantages of large ships without requiring super-ports or extensive dredging of harbors to accommodate them. Increases in deadweight of 50% or more, without changing draft, are possible with this technology[8]. However, the resulting large length to draft ratios will result in hull flexures and whipping stresses not previously encountered, and will require special consideration.

Another means of realizing great improvements in productivity with dry bulk commodities is to change the form of the commodity to a liquid to facilitate handling. This process was extensively investigated by Litton in 1973, where such commodities as slurried coal were found to offer great promise for future ocean transportation[9]. The principal advantage of the slurry process is that for the same cargo handling capacity the required equipment is considerably less bulky and less costly than the corresponding dry bulk handling equipment, with cost savings of 50% appearing likely. Therefore, the next twenty-five years should see a considerable increase in the application of marine slurry systems. The selection of pump and piping materials to handle

FIGURE 5

OCEAN GOING DRY BULK SELF UNLOADING CAPABILITY



slurried commodities will be a challenge to the metallurgist.

Neobulk Shipping—This category consists of cargoes of low to medium value, that are available in medium lot sizes. Slow to medium service speeds with flexible scheduling is generally required. Low transportation cost is important here, and must be attractively below general cargo liner freight rates to attract this cargo. Examples of neobulk cargoes are sugar, lumber, fruit, scrap iron, and automobiles. The expected growth in these cargoes is shown in Figure 6, which indicates that many of these cargoes will be available in sufficient volume to warrant their more efficient transportation in specialized vessels. Shipping cargo in specialized vehicles offers a considerable economic advantage since special preparation of the cargo is virtually eliminated. These specialized ships will, as a class, have very large hatches to speed the cargo handling process, and many will make use of heavy lift gear for the same purpose.

For those neobulk cargoes where specialized ships are not warranted, integrated tug-barges should be increasingly used. An integrated tug-barge system couples the propulsion unit to the cargo-carrying unit in such a manner that both the propulsion and cargo-carrying units form one integrated hull. The advantage of this concept is that only the relatively inexpensive cargo-carrying barge unit need be subjected to cargo-handling delays, while the relatively expensive propulsion tug can continue to be utilized. Integrated tug-barge units are being increasingly utilized, and by 1985 they should be found

FIGURE 6

NEO-BULK CARGO TONNAGE

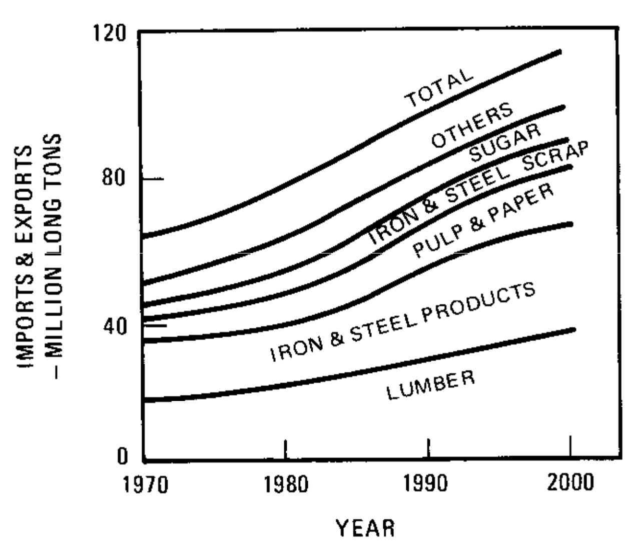
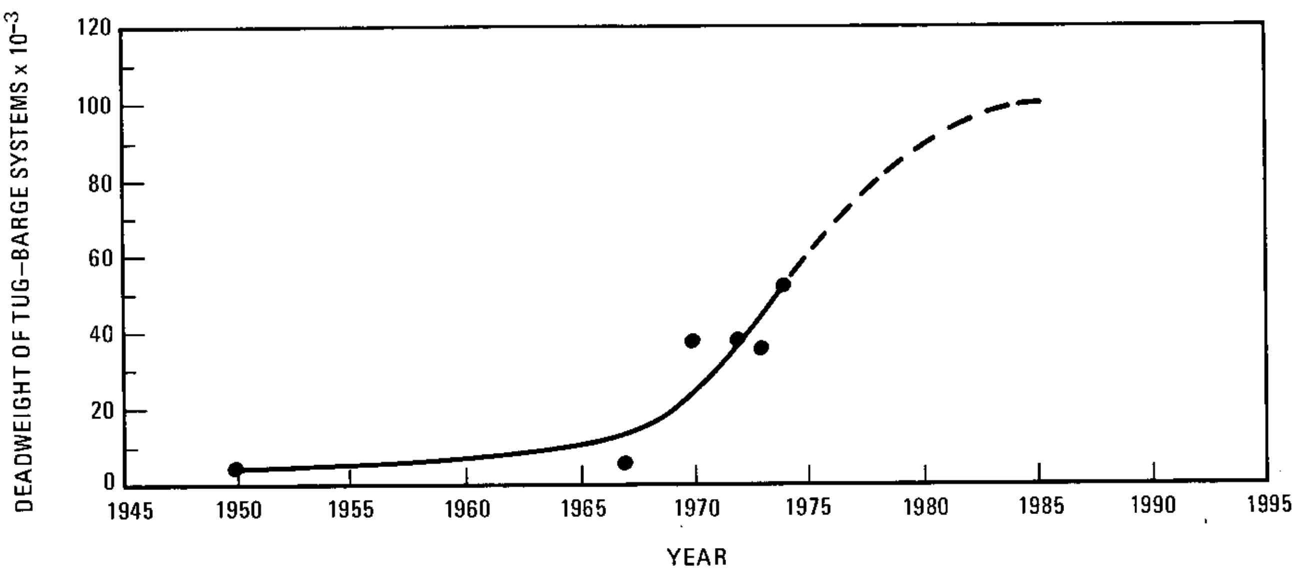


FIGURE 7

MAXIMUM DEADWEIGHT OF INTEGRATED TUG-BARGE SYSTEMS FOR FEEDER SERVICES



in sizes of up to 100,000 DWT (see Figure 7). However, critical structural design problems exist in the notch area of the barge units, and these problems must be resolved before the large units come on line.

General Shipping–General cargo covers the entire range of the commodity value spectrum from low value break-bulk items such as animal feeds to high value manufactured goods. However, the character of this shipping category is expected to narrow as some of the lower-value commodities increase in quantity to the point that they are classified as neobulk, while some of the higher valued commodities become part of the express cargo market. Nevertheless, what remains is substantial, and is expected to increase almost fourfold by the end of the century (see Figure 8). As a shipping service, general cargo requires closely maintained schedules and medium to high transit speeds. Transportation costs tend to be high, with freight rates subject to government or conference regulation. This cargo generally travels in medium to high speed displacement ships operating out of ports having rail and highway connections.

The handling of cargo is of the greatest importance in the general cargo shipping area, since it accounts for 40 to 60% of the total system operating cost, and has therefore been the driving force behind the development of new shipping system designs such as container, LASH, SEA BEE, Ro-Ro, and trailer systems. The area of greatest technological improvement in commercial shipping in recent years has been in the handling of general cargoes. For example, the handling of general cargoes in containers rather than in the break bulk mode has been instrumental in increasing the annual production capability of general cargo vehicles by a factor of ten between a World War II C-2 and the latest 3,000-unit capacity containerships.

FIGURE 8

GENERAL CARGO TONNAGE

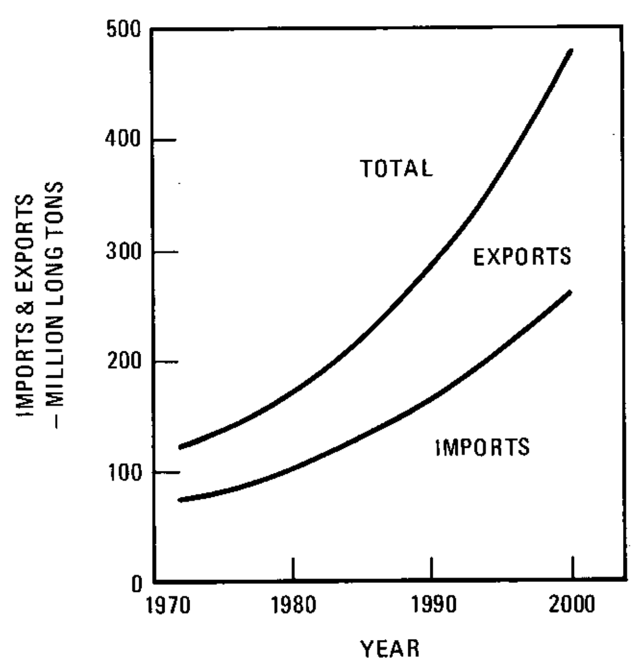


Figure 9 shows the approximate time that each general cargo handling mode came into existence, and the approximate range of productivity in tons per manhour of longshore labor. This measure of productivity includes both the tons per hour handled and the number of longshoremen required. It can be seen that there has been almost a hundredfold productivity increase over the past quarter century, although this figure is slightly misleading since the productivities shown for container, trailer, and barge-ship operations include only the time required to lift or drive the units onto or off the ship, not the time to stuff the unit.

Focusing on the containership, the tremendous productivity increase achieved by these ships during the late sixties and early seventies was due to both an increase in speed and carrying capacity. Containerships have grown in capacities from 100 to 3000 twenty-foot units, and in speed from 15 to 33 knots. This increase in ship production capability (measured in annual ton-miles) can be seen in Figure 10. This rapid increase is likely to level off till the late seventies, when the demand for general cargo transportation on the major North Atlantic and Pacific routes catches up and surpasses the present and near-term overtonnage. Containership production capability can then be expected to increase again, so that a vessel productivity of about 18 billion ton-miles per year by the year 2000 appears realistic. This could be achieved, for example, by doubling either the size or speed of an SL-7 type containership, or more likely, some combination of both.

FIGURE 9

PRODUCTIVITY FOR GENERAL CARGO HANDLING SYSTEMS

(TONS/MAN–HR)

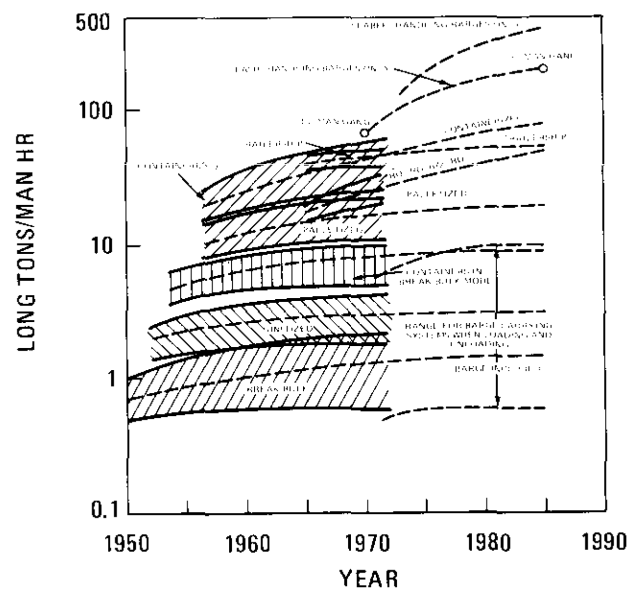
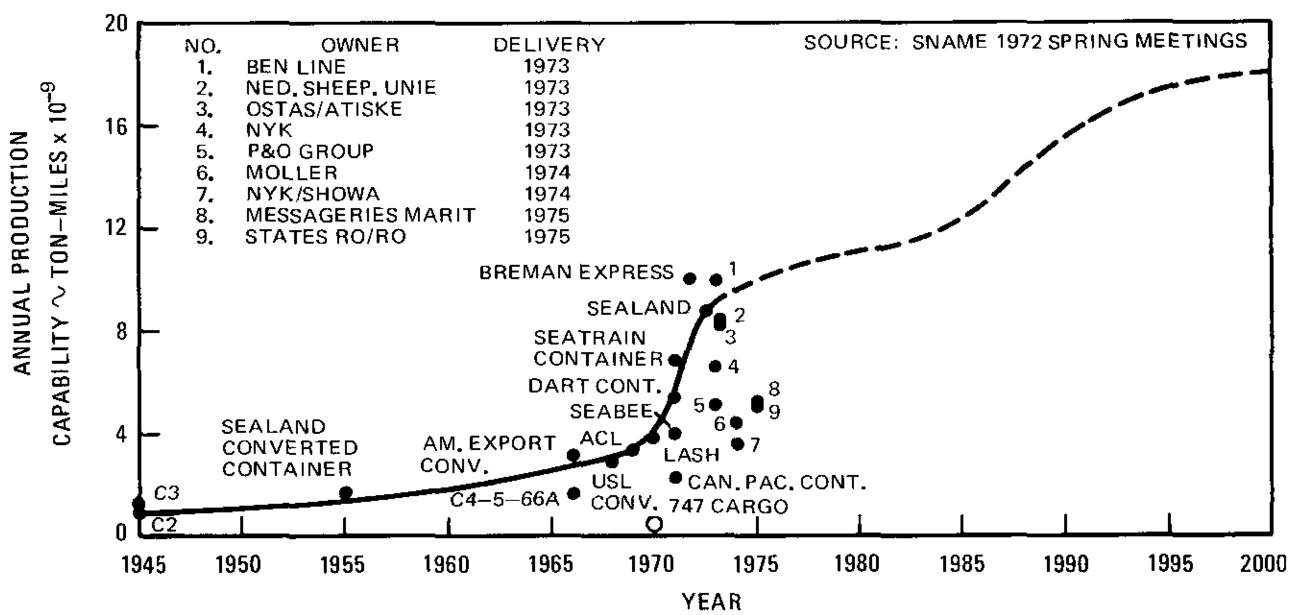


FIGURE 10

ANNUAL PRODUCTION CAPABILITY OF GENERAL CARGO VESSELS

(TONS CAPACITY x DAILY MILEAGE x DAYS AT SEA/YEAR)



The great increases in speeds of containerships is a result of this service being a very competitive one. The shipper, of course, is interested in seeing his goods move as rapidly as possible. Since all container freight rates are identical for the same route, the fact that a shipper may be able to have his goods get there a day sooner for the same price is a sufficient incentive for him to ship his goods on the fastest vessel. This competition among containership operators, plus the increasing competition from air freight, has driven the speeds of containerships to values approaching the present technological limits of displacement hulls and propellers. For example, the latest Sealand SL-7's are capable of speeds up to 33 knots, but require a twin-screw power plant transmitting 60,000 SHP per shaft, which is close to the limit of today's technology. The doubling of containership power, which has occurred over the past decade (see Figure 11), is obviously not going to continue, since these ships are now at the point where slight increases in speed can only be bought at the price of high increases in required power. An SL-7, for example, would require an increase in power from 120,000 to 200,000 SSP to increase its speed from 33 to 37 knots. It can therefore be reasonably assumed that past 1985, speeds above 37 knots will not be achieved with conventional displacement hulls.

Another factor that strongly affects containership speed is ship displacement. A reduction in displacement results in lower required power, which is a significant factor for these ships due to their high fuel costs. A reduction in displacement can be obtained through a reduction in ship structural weight, and the trend in structural weight divided by displacement has been downward for containerships over the past few years (see Figure 12). This downward trend should continue, but since many containerships have stability problems, attempts at structural weight savings will probably be concentrated in "high" areas, such as deckhouses, where light weight, high strength materials will find increasing use.

In other general cargo categories, the acceptance of barge carrying ships will grow, and will tend to capture the lower value end of the general cargo and neobulk spectrum. Innovations in this area will come in the development of feeder systems for the barges, thereby permitting the large, capital intensive barge carrying ships to

FIGURE 11

FREQUENT MAXIMUM CONTAINER VESSEL INSTALLED HORSEPOWER

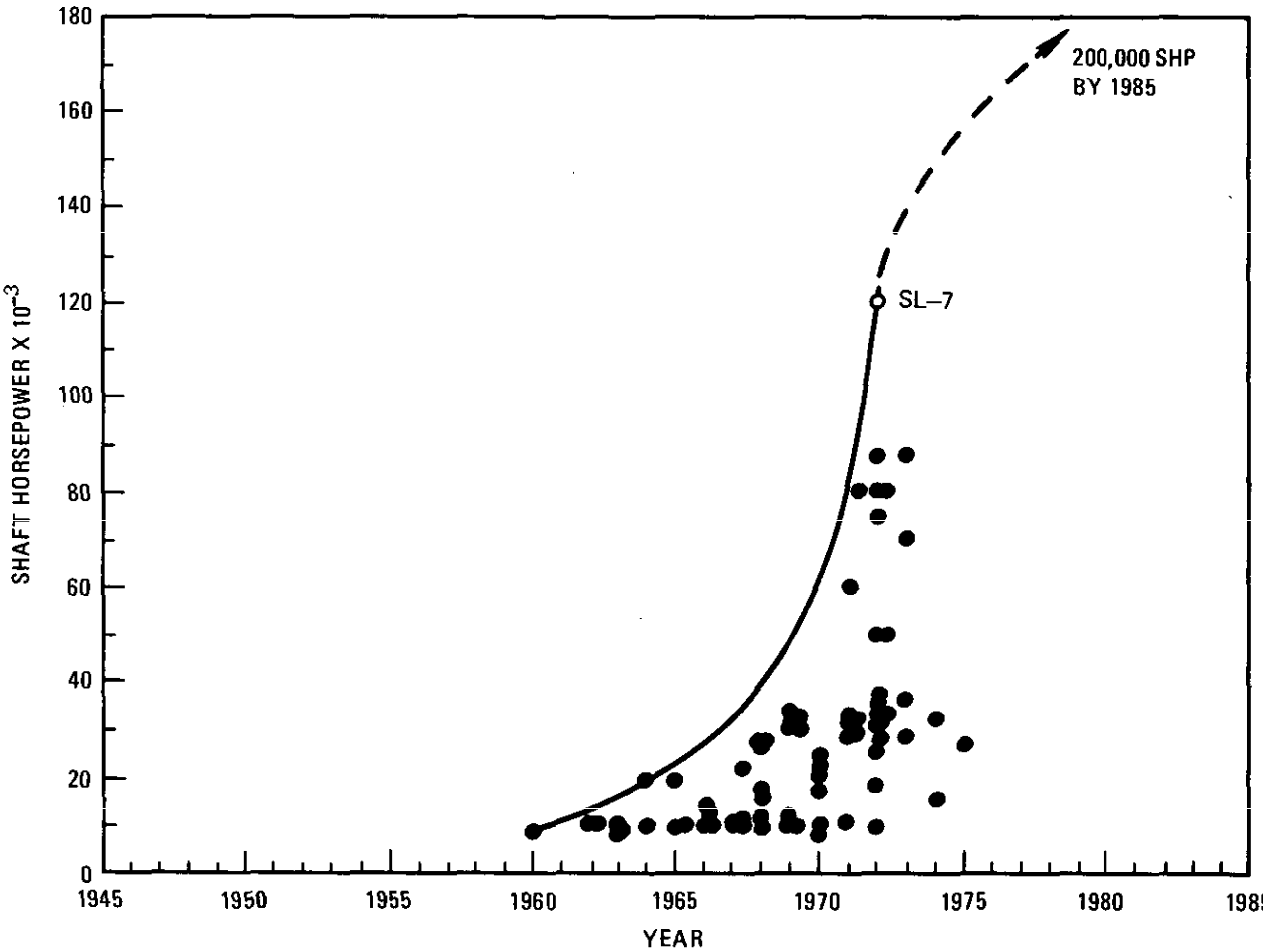
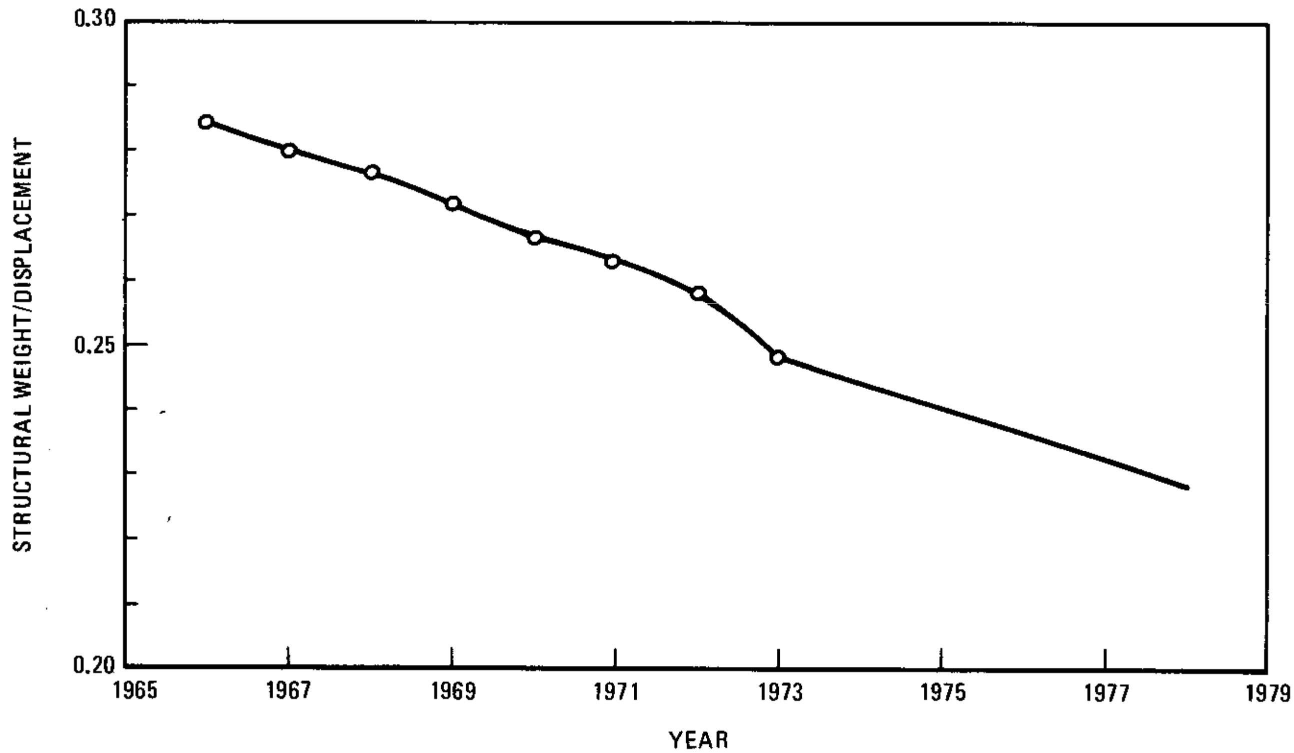


FIGURE 12

STRUCTURAL WEIGHT/DISPLACEMENT vs. YEARS FOR CONTAINER SHIPS OF 12,000–30,000 DISPLACEMENT



operate economically between a limited number of "express" ports. The use of break bulk ships for general cargo can be expected to continue to decline, as the barge ships and containerships take the greater portion of this cargo. The cargo that will remain for the break bulkers will tend to be the awkward sized, heavy weight items, requiring heavy lift gear, that cannot be accommodated in other ships.

Express Shipping–This category is fairly new but rapidly growing. It is expected to increase tenfold by the year 2000[1]. It consists of very high value (high inventory cost) cargo available in small lot sizes. This cargo requires custom origin to destination service at high speeds, and on frequent intervals. Examples of express cargo are electronic gear, scientific instruments, medicines, computers, and watches. The greater the value of a commodity, the greater is its time value, and the greater is the incentive to reduce the time in inventory and shipping.

Express ocean shipping services come close to competing directly with air freight for cargo. Over the past decade, the battle has been a losing one for the maritime industry, as airborne foreigh commerce has increased dramatically. Figure 13 indicates that based upon recent trends, air freight should carry 50% of the value of all foreign commerce in the year 2000, unless a revolutionary change occurs in the type of service offered by our merchant marine. At present, a large performance gap exists between ocean shipping services and air freight. The fastest merchant ship today is capable of 33 knots, while a jet cargo plane travels over 500 knots. It is this gap which an ocean express system must fill. The potential to fill this gap exists in high speed displacement ships on the lower end, and in the large surface effect ship, the technology of which is being developed by the U.S. Navy, on the upper end.

United Aircraft[1] performed an economic study of the various competitors for the express cargo market. Their analysis included:

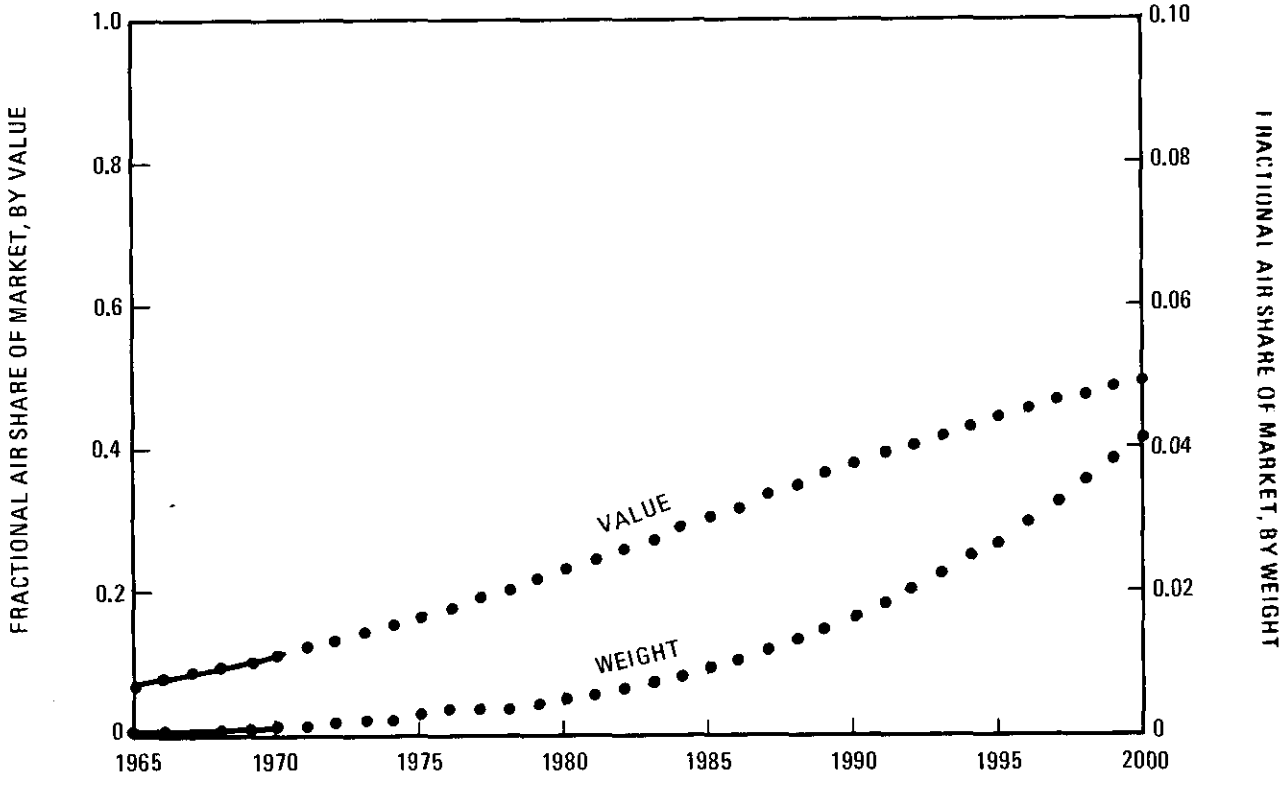
Displacement Ships: a present-day general cargo ship (labeled a "historic ship"), and a projected 1990's container-ship.

Surface Effect Ships: a 1,000 ton payload and a 3,000 ton payload SES, using 1990's technology and traveling at 100 knots (characteristics provided by Bell Aerosystems).

Aircraft: a Boeing 707F, A Boeing 747F, and an advanced cargo aircraft using 1990's technology (characteristics supplied by McDonnel Douglas).

FIGURE 13

TRANSOCEANIC AIR FREIGHT IMPORT/EXPORT MARKET PENETRATION



These alternatives were compared on the basis of total transportation cost (dollars per ton) versus the value of time (dollars per ton-hour) for goods in transit. This latter parameter recognizes the fact that for high valued cargo, transit time has a certain "inventory cost." For any given value of time, the transportation mode with the lowest total cost is the most desirable. The results of the study are interesting. Figure 14 shows the comparative results for a long transoceanic route (New York to London). It indicates that at the end of the century express cargo with a low time value should continue to be shipped on containerships, while high time-value cargo should travel on cargo aircraft. However, for shorter routes (New York to Puerto Rico), Figure 15 indicates that a large market should exist for an advanced 3,000-ton payload surface effect ship, even when compared to advanced containerships and advanced cargo aircraft. This result is important because the U.S. conducts a considerable amount of domestic waterborne commerce. By the year 2000, the total domestic waterborne commerce should build up to about 1.3 billion tons(1). If a significant percentage of this market is in high valued goods, an express cargo system based on surface effect ships or small, fast displacement-hull ships would become a competitive transportation system.

FIGURE 14

ECONOMICS OF ALTERNATIVE CARGO TRANSPORT MODES

N.Y.–TO–LONDON ROUTE
(3000 NM GREAT CIRCLE DIST.)

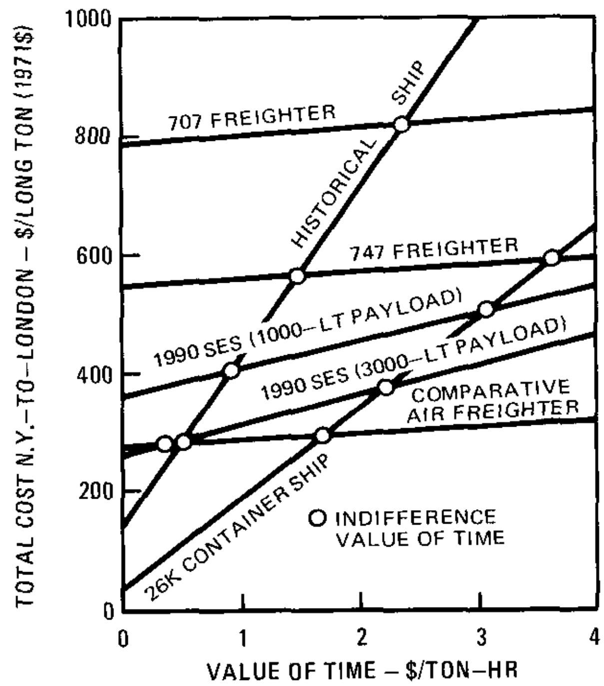
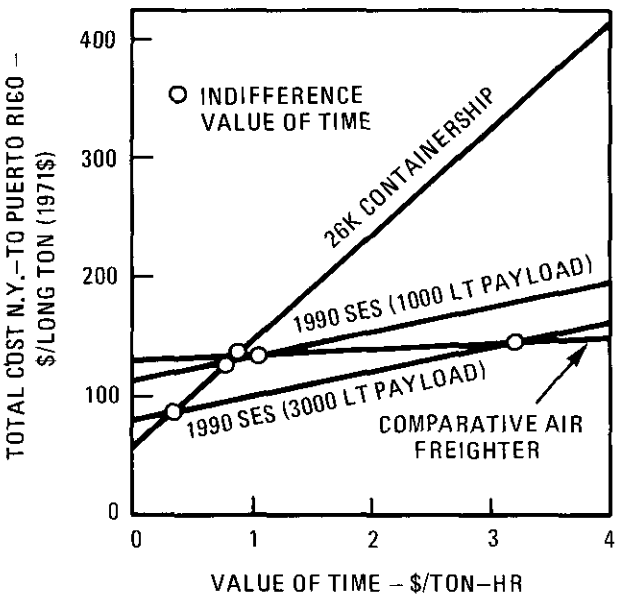


FIGURE 15

ECONOMICS OF ALTERNATIVE CARGO TRANSPORT MODES

N.Y.–TO PUERTO RICO ROUTE (1400 NM)



OFFSHORE STRUCTURES

Human civilization has always been linked with the oceans. The oceans were the pathways which led early explorers to new lands and new resources. Today the oceans link the world's commerce, temper our climate, and provide food, salt, and energy. Tomorrow the oceans are destined for additional roles as a direct source of water by desalination, as a support and pathway for power plants, as a means of increasing our available land, and as a tolerant acceptor of the waste heat burdens of our industrial world.

Energy Production–Since the first offshore oil well was drilled in 1947, the offshore oil industry has grown at an explosive rate. Last year, 212 offshore rigs were in operation, and offshore sources produced 20% of the world's total oil output. By the late 1980's offshore wells will account for up to 50% of the world's production[10]. A production jump of this magnitude would require construction of more than 500 additional mobil rigs, as well as a huge increase in fixed platforms. The growth in drill rigs and production platforms will cause an even greater demand for offshore support vessels. In the North Sea, for example, the average support fleet required per rig is 2.5[11]. These support vessels cover a wide range of requirements, from tugs to pipe laying ships, and from personnel boats to fire boats and lifting barges. Designing and producing these support craft will be both an opportunity and a challenge for the maritime industry.

Regarding rigs and platforms, minor extentions of present technology should make all of the world's continental shelves and continental slopes (those areas between the continental shelves and the ocean deeps) available for exploitation. Jack-up rigs, for example, are ideal for drilling in waters up to 300 feet deep, and are being improved. The future should see jack-ups capable of 500 feet and more. As water depths increase semi-submersible rigs and drilling ships are required for exploratory work. Semisubmersible now routinely handle water depths up to 1,000 feet, but depths as great as 3,000 feet are felt to be not beyond present technology[10]. Beyond the range of the semisubmersible, the drill ship is required. The Royal Dutch/Shell group has already successfully used an unanchored drill ship, using computer controlled dynamic stationing, to reach depths of 1,400 feet, with the limit on depth capability now becoming riser design rather than ship performance. Risers can now handle water depths up to around 2,000 feet. With floatation devices, the current basic designs could likely be extended to around 3,000 feet[10]. Beyond 3,000 feet, a new concept may be required to provide the connection between the sea floor and the rig bottom.

Looking beyond the continental slopes, to the very depths of the oceans, the concept of undersea production holds great promise. The current problem is that while today's technology can be extended to the point where well drilling in several thousand feet of water is feasible, the job of placing platforms to retrieve the oil is a formidable task, particularly in hostile offshore areas. Lockheed and Shell are jointly working on a project that will see a habitable production station, containing pumps and compressor equipment, working on the ocean floor. Crew men would travel down to the production station in a transfer bell winched down from the surface[12] With a slight extension of imagination, one can envision ocean floor drill rigs and production stations working beneath the Arctic ice fields, transferring their production to a fleet of waiting nuclear powered submarine tankers. If oil supply is to keep up with projected demand, serious planning must begin now to exploit the oil in these formidable regions.

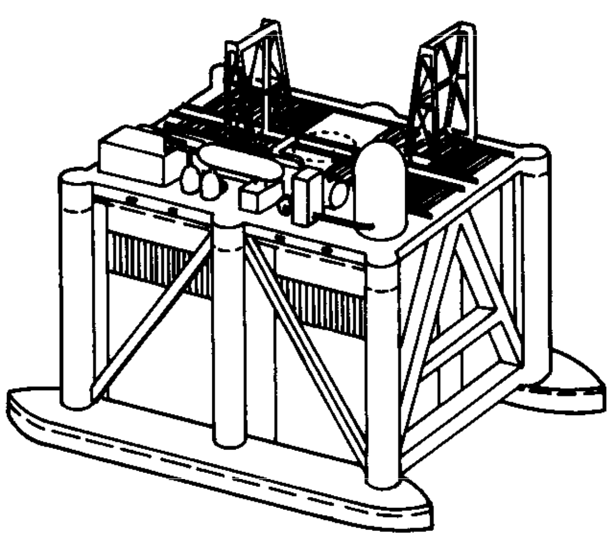
Mining–Less than 2% of the world's mineral production comes from marine sources. This, however, will increase rapidly as land-based mineral sources are exhausted. First to be mined commercially will be manganese nodules, which lie, grapefruit size, on the ocean floors through the world. These nodules contain useful quantities of manganese, iron, nickle, copper, and cobalt. Before the operation can be performed profitably, however, considerable problems in mining, processing and transportation must be solved. Once these problems are solved, attention will shift to other minerals known to exist in large quantities under the sea. The entire operation will require engineer and scientist to work together to solve some extremely challenging problems.

Power Production–Several schemes have been proposed to produce power from the energy in the seas. Tidal energy, for example, has been used to commercially produce power in northern France for many years.

Currently, the most promising means of producing power from the sea itself appears to be in the area of ocean thermal energy conversion. By utilizing the differential in temperature between the ocean surface and ocean depths to drive a refrigeration-type Rankine cycle utilizing ammonia as the working fluid, it is technically fesaible to generate enormous quantities of power at a relatively low cost (4 to 6 mills per kwh according to the Applied Physics Lab[13]). It has been estimated that a power generating capability equivalent to at least 10 times the whole world's energy needs in the year 2000 exists in the tropical seas between 10°N and 10°S latitudes. Thus, use of just a very small percentage of this potential could make a substantial contribution to the world's energy problems. While it may be infeasible to directly transfer power from equatorial ocean thermal plants to densely populated areas, such plants could be utilized as floating factories producing energy intensive products. For example, an ocean thermal plant could provide ammonia (used in fertilizers) from sea water and air, or could be used to produce aluminum from bauxite, thereby freeing large amounts of energy for domestic uses. An artist's concept for such a plant is shown in Figure 16. This entire areas has so much promise for solving some of our national problems, that it should be pursued on a crash-basis.

FIGURE 16

CONCEPT OF TROPICAL OCEAN THERMAL ENERGY PLANT



City Services—With more than half the U.S. population living in counties bordering the sea or the Great Lakes, the oceans also offer a potential for removing sources of social annoyance from inhabited land masses. These include nuclear power plants, airports, sewage treatment plants, and incinerators. Offshore floating service platforms to house these facilities can at once be close to their users, yet conveniently removed so as not to cause a nusiance. The first floating service platforms may be built in waters from 40 to 70 feet deep, so that conventional breakwaters could be used to provide protection from storms or ship collisions. Later designs may be in deeper water where breaking waves would not be encountered[14]. In this situation, the possibility arises of using no breakwater at all, but of building instead a containment hull designed as its own bulwark against the sea. The cost saved from the breakwater could be used to make the service platform larger, stronger, and equally wave resistant. Ship collision protection for such deep water platforms could then be obtained from a barrier consisting of a ring of floating buoys carrying heavy cables connected to drag anchors at the sea bed. Once the technology is developed to produce these service platforms, economic forces will tend to combine the power station, maritime terminal, sewage treatment plant, etc., to produce a huge floating complex several square miles in size. These industrial parks in the sea could once again make our coastal cities desirable places to live.

CONCLUSION

The intention of this paper is not to accurately forecast the future, but to point out several directions in which our technology and our nation's needs appear to be taking us. Some immense technical problems must be overcome before we enter the marine era of the Twenty-First Century. In the structural area, great advances will be required in many areas, including a better understanding of ship vibrations, hull flexure, dynamic structural response, stress corrosion, and fatigue, as well as development of high-strength, light-weight materials, development of corrosion resistant low-temperature materials, and development of improved methods of material fabrication. It is hoped that those who are formulating tomorrow's research programs will do so with a view toward what technologies will be required in the future, rather than what was needed in the past.

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