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RESEARCH IN NAVAL ARCHITECTURE AND MARINE ENGINEERING

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Preface

The Department of Naval Architecture and Marine Engineering of The University of Michigan conducts a vigorous program of research in problems related to ship technology, for the sake both of advancing that technology and of keeping our educational program in tune with the times. We present here a report on our research effort, so that our alumni, our colleagues in other institutions, and our friends may have some idea of the scope and depth of the areas in which we are working.

The articles contained in this report were selected from a wide range of possible subjects. We wanted to present some topics in enough detail so that interested readers could obtain some real understanding of what the research is all about. This intent precluded our publishing a comprehensive description of all of our research projects. The articles here are representative only. In the future, we expect to describe other projects in a similar way, and we hope thus to do justice to the topics that are ignored or glossed over in this report.

We have attempted to prepare these articles so that each would be self-contained and intelligible to a professional naval architect or marine engineer. This goal has required that many important technical considerations be discussed only in rather general terms. Readers who want more specific information will find references in the individual articles.

The single most important outlet for our technical work is the series of reports published by the Department. This series was started in 1968, and we have now published more than 150 issues. A complete list is included in this report. (The series contains a number of didactic works, as well as some translations and occasional reprints of selected papers.)

Doctoral and professional degree theses represent an important segment of our research output. A list of all such theses since 1960 will be found in this report. (Many are essentially identical to reports in the Department report series. Most of the others can be obtained from *University Microfilms* in Ann Arbor.)

Otherwise, our technical output appears in numerous standard journals and in the transactions of various symposia. A list of recent such papers by members of the Department is included in this report.

We welcome comments and constructive criticism of our research program and of our reporting on that program. It should be recognized that we have imperfect control over the topics of our research, since we are often constrained to investigate those problems for which we can find sponsors external to the University. Nevertheless, we invite you to express your reactions to this report and to our program in general.

As department chairman, I personally add an invitation for you to comment on all aspects of the program of the Department of Naval Architecture and Marine Engineering. This report happens to concern our research, but that is just one part of our program. Our primary effort is still devoted to teaching naval architecture and marine engineering, and the justification for our having a research program comes mostly from its contributions to our educational program. We are dedicated to carrying on a balanced program at all levels from freshman to post-doctoral. I shall thank every one of you (personally if at all possible) for your advice and your support.

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Ann Arbor

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The Fleets of Winter

Harry Benford

Seafaring men the world over revere their traditions and are loathe to change their ways—often justifiably so. On our inland seas, however, a remarkable upheaval is taking place, and the impetus for it is sheer economic necessity.

The predominant commerce on the Great Lakes is the transport of iron ore from the upper end of the lakes to the steel mills at the lower end of Lake Michigan and around Lake Erie. In the past, the ore from the upper lakes held a monopolistic position. Now, however, many of the mills can buy ore from foreign mines at competitive prices. The foreign ores enjoy the advantage of highly efficient transport in deep-draft ocean carriers. Typically, these ships have drafts of 60 feet and deadweights of 160,000 long tons. On the lakes, however, shallow harbors and channels limit the ore carriers to drafts of 27 feet and deadweights of less than 60,000 long tons. Thus, although geographic distance favors the domestic ores, the economies of scale favor the larger foreign ships. The salt water ships, moreover, can prorate their capital costs over a full year's operation, whereas the lakers have traditionally been limited to an eight-month season. It is that tradition that must now give way if our domestic iron mines and Great Lakes commerce are to survive.

The seeds of change were planted in 1959 by Admiral Edward H. Thiele, who was then the U.S. Coast Guard's top officer in the Great Lakes region. He pointed out that winter navigation should be possible on the lakes. I contributed cost studies that predicted the economic feasibility of Admiral Thiele's proposal. Professor John Hazard of Michigan State University then called attention to the macro-economic benefits of extending the season through the St. Lawrence Seaway as well as on the lakes themselves.

All of this remained just talk until 1967 when the managers of the U.S. Steel Corporation fleet undertook to keep some of their better ships operating past the traditional mid-December deadline, until early January. Feeling their way along with due caution, they have since operated a little later each year. During the 1972–73 season, they continued until mid-February. With their subsequent spring start-up in late March, U.S. Steel could claim that there was no month in the past year when their ships were not in action.

The U.S. Steel experiments showed that Admiral Thiele was right: Ice is not the insurmountable obstacle previously supposed, and year-round navigation is indeed possible. True, there are ice-choked areas such as the St. Mary's River and the Straits of Mackinac. (See Fig. 1.) Even at the time of maximum ice cover, however, over 80 per cent of the journey is in open, ice-free water.

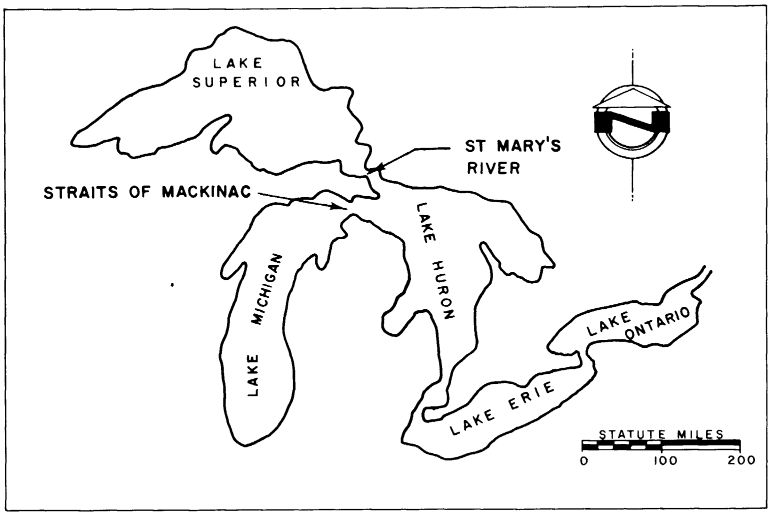

FIGURE 1 The Great Lakes
Iron ore is carried from western end of
Lake Superior to the lower lakes

U.S. Steel Corporation has concluded that the proper way to extend the season is to run late (January and February) rather than to start early (March). The greatest dangers come in the early starts, when the ice cover breaks apart and drifts. Surprisingly, too, the slush-filled waters of spring can stop a ship as effectively as solid ice. However, such difficult conditions are isolated both in location and in time. Thus, although the spring break-up poses temporary problems, they do not preclude the feasibility of year-round navigation on the lakes. Whether the same will prove true on the St. Lawrence Seaway remains to be seen, but there is reason for optimism.

The continuing success of the U.S. Steel fleet quickly attracted the attention of midwestern industrial leaders such as Dow Chemical and Huron Cement. Traffic managers saw the marketing benefits of year-round navigation on the lakes and the Seaway; this led some of them to organize a consortium dedicated to encouraging that development. The users group soon won the backing of the Michigan State Chamber of Commerce and of the Great Lakes Commission. Since the cooperation of several federal agencies was required, these industrial leaders convinced Congress to support a multi-year winter demonstration program that is still underway. The program involves the U.S. Army Corps of Engineers, the U.S. Coast Guard, the National Oceanic and Atmospheric Agency, the Environmental Protection Agency, the Maritime Administration, and others. Comparable Canadian agencies are also in the act.

The interest of the Maritime Administration focuses on the technical and economic problems of the ships of commerce. For its part, then, the Maritime Administration is sponsoring experimental research in icebreaking characteristics, both in this country and abroad. It is also sponsoring a continuing techno-economic study here in The University of Michigan's Department of Naval Architecture and Marine Engineering.

Our responsibility is to provide the analytical tools that will help the government predict the economic benefits of winter navigation. To this end we have developed a comprehensive procedure for estimating the profitability of a ship (whether proposed or in existence) operating in season extensions of various lengths, on different trade routes (still all intra-lake), and with various levels of government support in icebreaker assistance, aids to navigation, and so forth. This has required parametric analyses of structural hull requirements, ship weights, building costs, operating costs, ice conditions, round-trip times, and annual transport capability. The necessary volume of calculation is such that computer assistance is mandatory. A large share of our work, then, has been to develop a computer program suited to the University's IBM 360/67 computer system. Most of this programming has been done by a team of graduate students under the guidance of Professor Horst Nowacki, co-director (with me) of the project.

Preliminary applications of our computerized analysis have illuminated the importance of breaking away from traditional, narrow concepts in ship design. If we look at a single ship, for example, we find relatively modest advantages in winter navigation, as indicated in Fig. 2. If we look at an

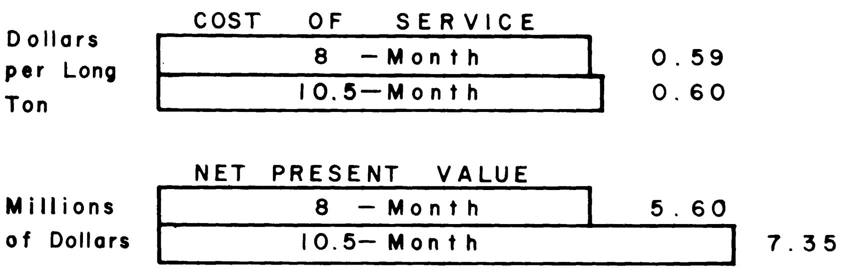

FIGURE 2 Economic Gains from Extended Season
Figures indicate economic benefits for a single ship

entire fleet, on the other hand, we find that the extended season offers appreciable gains in profitability. This is because the longer season allows the shipowner to maximize the use of his most productive ships, placing less reliance on his older, less efficient units.

An even greater advantage accrues to the steel mill. The old eight-month operating season required enormous stockpiles of iron ore, coal, and limestone, so that the mills could continue production throughout the year. Stockpiles mean money tied up in operating capital, which must bear interest charges based on the corporation's cost of capital. Our calculations show that the mills' annual inventory savings (made possible by the extended season) are at least twice as great as the savings attainable by the fleets. The savings for just one steel mill would be measured in millions of dollars per year.

With the continuing encouragement of the Maritime Administration, we pay close attention to the needs of industry. We keep in close contact with shipowners, shipyards, and design offices around the lakes. Our reports, which are freely disseminated, are written with that audience in mind. Moreover, we are now prepared to bring a portable computer terminal to the office of any interested party and demonstrate the use of the program. In fact, the program can provide valuable benefits in ship design regardless of whether winter operations are even intended. We are now working with the shipowners to find the most economical way to service steel mills located on restricted waterways unreachable by the newer and more efficient 1000-foot carriers. We are also providing liaison with environmental groups that are understandably concerned about possible harmful effects of disturbing the natural ice cover.

Our project team, now in its third year of action, has completed most of the computer work related to Great Lakes bulk carriers and it is starting to study problems involving the St. Lawrence Seaway. Looking ahead, we believe that we can and should broaden our scope of action to encompass complete source-to-destination transport systems. We shall maintain our interest in ice navigation, but we shall not confine ourselves to it. As one step toward increasing our versatility, we have already entered the area of rail transport economics, and we have published what we believe to be the definitive treatise on unit train economics (Ref. 1). More generally, we are developing a comprehensive transport research team with special expertise in the problems of the Midwest.

Encouraged at least in part by our economic projections, Great Lakes shipowners are now embarked on a vigorous shipbuilding activity. They are convinced that the extended saeson will make their investments profitable. The shipbuilders are obviously benefiting, and so are the ships' crews, who face shorter periods of unemployment (but who understandably want some form of relief from uninterrupted shipboard duty). Likewise, the iron miners of the Lake Superior region enjoy a new advantage in their competition with foreign ores, while the steel mills can exploit major savings in inventory costs. Most of all, however, the public can look forward to less inflation in costs of consumer products. The University's research into winter navigation represents one research investment that is producing highly satisfactory returns to the investor: the American taxpayer.

* * * * *

The reports on the most recent phase of the Department's project on the extended operating season are listed below as References 2–6. They can be obtained from the Department, as explained in the Appendix, which lists all Department reports.

REFERENCES

1. Sward, John D., "Unitrain Operating Methods and Costs," Report No. 145, Department of Naval Architecture and Marine Engineering, The University of Michigan (1973).

The following reports constitute a five volume series entitled "Great Lakes Winter Navigation—Technical and Economic Analyses," published by Department of Naval Architecture and Marine Engineering, The University of Michigan:

2. Vol. I: "Methods of Evaluation," Horst Nowacki, Harry Benford and Anthony Atkins, Report No. 151, (1973).
3. Vol. II: "Computer Program—Documentation and User Instructions," Steve Callis, Pabitra Majumdar, Horst Nowacki, Benedict J. Stallone and Peter M. Swift, Report No. 152, (1974).
4. Vol. III: "Parametric Studies," Horst Nowacki, Report No. 153, (1974).
5. Vol. IV: "Strengthening of Steel Plates Using Ferrocement and Reinforced Concrete," Movses J. Kaldjian, William H. Townsend, Lawrence F. Kahn and Kiang Ning Huang, Report No. 154, (1974).
6. Vol. V: "Ice Strengthening of Ship Hulls Using Steel, Ferrocement or Reinforced Concrete," Movses J. Kaldjian and Kiang Ning Huang, Report No. 155, (1974).

Ice-Reinforcing of Ship Hulls

Movses J. Kaldjian

Synopsis. A techno-economic study of the operating season extension in the Great Lakes bulk trades necessitated finding systematically the extra weight required in ice-strengthened Great Lakes vessels. This led to the development of a design method and a computer program by which the ice reinforcements, using steel, ferrocement, or reinforced concrete, and their respective weight and cost can be calculated for a wide range of parametric variation.

Introduction; Scope. Extension of the navigation season on the Great Lakes, among other things, brings the ship in contact with ice and the problems associated with it. The chief concern of the structural designer is to make sure that the ship scantlings are strong enough so that it can stand the additional forces produced because of the ice pressure.

Since ice conditions are never the same and are seldom predictable, it is not very realistic to model a uniform ice field and establish design ice pressures from it, although such a study will no doubt give some valuable information.

The approach to ice strengthening depends on the operating intentions of the ship owner. When ice conditions get to be bad, a ship can always slow down, then stop—preferably in fast ice—and wait for ice breaker assistance. This situation requires strengthening the ship sufficiently to enable it to survive without damage the ice pressures that are generated around its ice belt. On the other hand, if the ship owner is anxious to keep his ship moving in bad ice conditions, in order for it to reach its destination as quickly as possible, the captain may resort occasionally to ramming the ship through ice ridges. To accomplish the latter without damaging the ship requires heavier structural reinforcing than in the previous case. There are economic tradeoffs between the two extremes mentioned, and the ship owner must consider these before he decides how much to ice-strengthen his ship.

The weather conditions of the Great Lakes are similar to those of the Baltic Sea, the Gulf of Finland, and the Bay of Bothnia. The sizes of these bodies of water are comparable too. Finnish experience in winter navigation is drawn upon as background for the present study. The Finnish *Ice Rules** are based on information obtained from Lloyd's Register of ships that were actually damaged by ice. The Ice Rules specify the pressure developed be-

* The American Bureau of Shipping[1] adopted the Finnish Ice Rules *verbatim* in 1972.

tween the ice belt of the hull and the ice itself as a function of the displacement and shaft horsepower of the ship. Four ice classes are defined, each with different ice pressure requirements. In addition, the ice belt of a vessel is divided into three regions, forward, midship, and aft, with varying requirements. The forward region experiences the greatest pressure and the aft region the least.

A computer program has been prepared at The University of Michigan which can assign a different ice class to each region along the ice belt of a vessel and calculate the scantlings, weights, and costs accordingly. Such a hybrid arrangement may in some instances prove practical and economically advantageous to the ship owner. The purposes of this computer program are:

1) To calculate scantling and locations of reinforcing members and to obtain the additional weight and cost of steel necessary to reinforce an existing or proposed ore carrier or other vessel for any desired ice class as defined by the Ice Rules;

2) To determine the required reinforcement of ore carriers or other vessels using ferrocement or reinforced concrete as an alternative design, and to compute the relative merits of steel design with ferrocement and reinforced concrete for weight and cost;

3) To check the registered ice class of a ship using the actual ship data. (The additional reinforcement is calculated, and a zero or a negative answer indicates the correctness of the design.)

The program is geared to handle transversely and/or longitudinally framed vessels. Reinforcing weights and costs are calculated, first, by using Ice Rules shaft horsepower and, second, by using the specified (actual) shaft horsepower. The latter approach is believed to be more realistic, and we recommend its use for the ore carriers on the Great Lakes.

Description of the Program. The following main steps describe the working of the program.

(1) It starts with the frame spacings, and, using the Ice Rules, calculates the required hull steel plate thickness, t_r, in the ice belt.

(2) If the existing thickness, t_e, is less than t_r, it adds an intermediate frame.

(3) Steps (1) and (2) are repeated until t_r is equal to or less than t_e. (Note: In a new ship design, the latter criterion may be modified, for it may conceivably be more economical or lighter to use thicker plates and fewer frames.)

(4) With the new frame spacing, the required modulus, S_r, of the frame is obtained from the Ice Rules.

(5) Then, from a list of angle and channel sections, starting with the lightest section and making use of effective plate width, it calculates the actual section modulus, S_a.

(6) If S_a is smaller than S_r, it picks the next heavier section from the list and recalculates S_a. This step is repeated until S_a is equal to or greater than S_r.

(7) Next, it obtains from the Ice Rules the required section modulus and the required shear area for the stringer, and it compares them with the actual section modulus and shear area calculated from the actual stringer cross-section and plate effective width. If the required values are greater than the actual values, one inch wide plate of existing hull plate thickness is added to the stringer flange and web incrementally until the design section modulus and the shear area are equal to or greater than the values required.

(8) Likewise for the transverse web frame, the required section modulus and shear area are obtained from the Ice Rules. The design section modulus and shear area are obtained following the steps described for stringer design in (7).

(9) Ferrocement and reinforced concrete design begins with step (1). If t_r is greater than t_e, the required bending moment M_r is obtained from $M_r = t_r^2 f_s/6$, where f_s is the yield stress of hull steel plate. The bending moment of the composite section (steel plate with ferrocement or steel plate with reinforced concrete)[2] is made equal to M_r, and, from it, the required depth of concrete is obtained.

(10) Steps (1) through (9) are repeated for all of the ice regions along the ice belt of the vessel and the weight and cost due to the added structural reinforcements are accumulated and printed out[3].

Results and Conclusions. Steel, ferrocement, and reinforced concrete weights and costs to ice-strengthen four Great Lakes ore carriers are presented in Table 1. Steel design is by far the lightest of the three. On the other hand, reinforced concrete and ferrocement designs are much less expensive. If a ship is volume controlled, reinforced concrete and ferrocement designs are found to be much more economical to construct than steel; otherwise, allowance must be made for lost ore or cargo capacity in the overall transportation economics.

For large ore carriers of the type presented in Table 1, variation in shaft horsepower has no bearing at all on the design ice pressures and hence on the added weight calculations.

Computer time on the IBM 360/67 to calculate the added weight and cost for one ice class is about four seconds of CPU (central processing unit) time.

Added steel weight calculations obtained from this program compare very

TABLE 1

Comparison of Steel, Ferrocement and Reinforced Concrete Added Weights and Costs to Ice Reinforce Four Great Lakes Ore Carriers

SHIP LBP BEAM DEPTH (FT)	ICE CLASS	WEIGHT IN LONG TONS			COST IN $1000			% GAIN	
		STEEL	REINF. CONCRETE	FERRO-CEMENT	STEEL	REINF. CONCRETE	FERRO-CEMENT	REINF. CONCRETE	FERRO-CEMENT
607	I AA	190	352	358	125.3	71.5	78.8	42.9	37.1
75	A(*)	165	305	308	108.7	63.7	69.8	41.4	35.8
42	B	114	234	235	75.0	45.6	50.1	39.2	33.1
	C	80	147	145	52.8	27.0	30.0	48.8	43.9
715	I AA	183	402	403	121.1	82.3	90.0	32.0	25.7
75	A	167	342	342	110.1	72.5	78.7	34.2	28.5
40	B	128	265	261	84.9	58.9	63.2	30.5	25.5
	C	80	147	121	52.8	27.0	32.9	48.8	43.9
837	I AA	246	471	473	162.6	92.3	101.4	43.2	37.6
105	A	209	401	400	138.0	80.2	87.6	41.9	36.5
47	B	168	305	299	110.9	62.8	67.8	43.4	38.9
	C	122	119	112	80.4	21.7	23.2	73.0	71.1
985	I AA	277	527	521	182.7	104.9	114.1	42.6	37.6
105	A	230	434	424	151.8	89.6	96.6	41.0	36.4
47	B	182	295	278	120.1	67.6	71.0	43.7	40.9
	C	85	134	134	56.1	33.2	35.4	40.8	36.8

NOTE: The figures above are for *Ice Rules* shp. The specified shp results were the same as above except for ship marked (*) which was off by a maximum of −3%.

well with other work done in this area, and they are being recommended along with ferrocement and reinforced concrete for preliminary design to the shipowner who is interested in ice-strengthening his vessel in part or in full.

References

1. American Bureau of Shipping Rules for Building and Classing Steel Vessels, 1972.

2. Kaldjian, M. J., Townsend, W. H., Kahn, L. F., & Huang, K. N., "Strengthening of Steel Plates Using Ferrocement and Reinforced Concrete," Report No. 154, Department of Naval Architecture & Marine Engineering, The University of Michigan, 1974.

3. Kaldjian, M. J., & Huang, K. N., "Ice Strengthening of Ship Hull Using Steel, Ferrocement or Reinforced Concrete," Report No. 155, Department of Naval Architecture & Marine Engineering, The University of Michigan, 1974.

Slender-Ship Theory

T. Francis Ogilvie

In the solution of ship hydrodynamics problems, several idealizations are generally made, simply because the exactly posed problems are too difficult to be solved. For example, in predicting wave resistance, ship motions, and wave loads by theoretical methods, one neglects the effects of viscosity. The results are never entirely satisfactory, but, without such simplifications, one can make no progress at all in the development of useful theory.

The ship hydrodynamicist eagerly seeks any valid means of simplifying his problems. One obvious aspect of the geometry of a ship that ought to be useful is the way in which the size and shape of the cross-sections change gradually along the length of the hull. Of course, this observation is not usually valid near the bow and the stern, but it is valid over most of the hull length, and so there should be some way to introduce it to good effect in the mathematical theory of ship hydrodynamics.

Aerodynamicists have faced similar problems for a long time. Fifty years ago, Munk (1924)[1] formulated a slender-body theory for the flow around "airships," using precisely such a geometrical simplification. Of course, he did not have to contend with the presence of an air-water interface (the *free surface*), but there are some useful analogies between airships and ordinary ships. His idea was developed to a sophisticated level in the 1940's and 1950's, for application to problems of delta-winged aircraft and missiles.

During the past fifteen years, the aerodynamical theory of the slender-body has been applied to ship problems extensively. In this article, I shall describe briefly 1) the genesis of the basic aerodynamic theory, 2) the formal application of this theory to problems of steady ship motion (with generally disappointing results), and 3) the development of the needed modifications to account for the influence of the air-water interface on the flow around a slender ship. In conclusion, I shall discuss briefly how these ideas are being applied to problems of ships in waves; it will be seen that the so-called "strip theory" of ship motions is a special case of slender-body theory.

Slender-Body Theory in Aerodynamics. Suppose that the body under consideration is "slender," that is, its transverse dimensions are small compared with its length. The body is moving steadily with speed U in the direction of the negative x axis, and the fluid is at rest far away. There is no free surface. We can view all of this on various scales:

1) If we are extremely far away, we can detect only that there is a moving disturbance. The streamlines may have the instantaneous appearance indicated in Figure 1, if the viewer is at rest with respect to the fluid at infinity. The

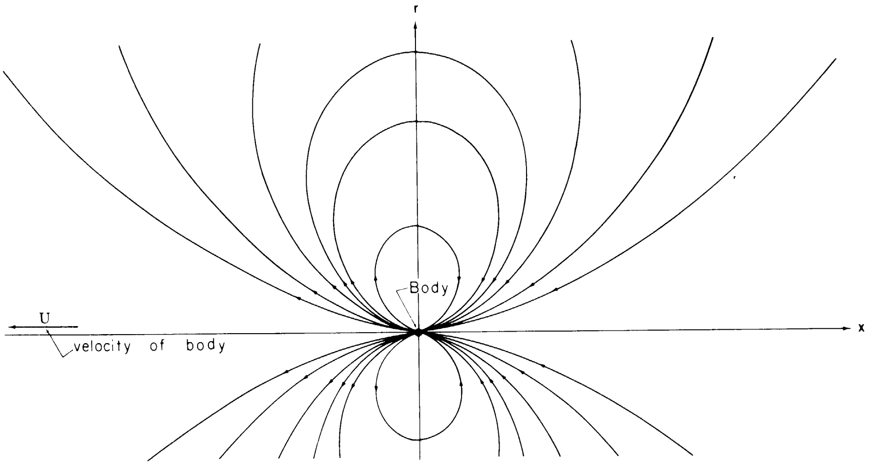

FIGURE 1 Far, Far View of Streamlines
Due to Body Moving Steadily to Left

sketch shows the streamlines at the instant when the body is located at the origin of the coordinate system. *Any* moving body could cause such a disturbance pattern; the body does not have to be slender.

2) If we are very close alongside the moving body, we see the fluid being pushed aside by the advancing body, as depicted in Figure 2. Since the fluid

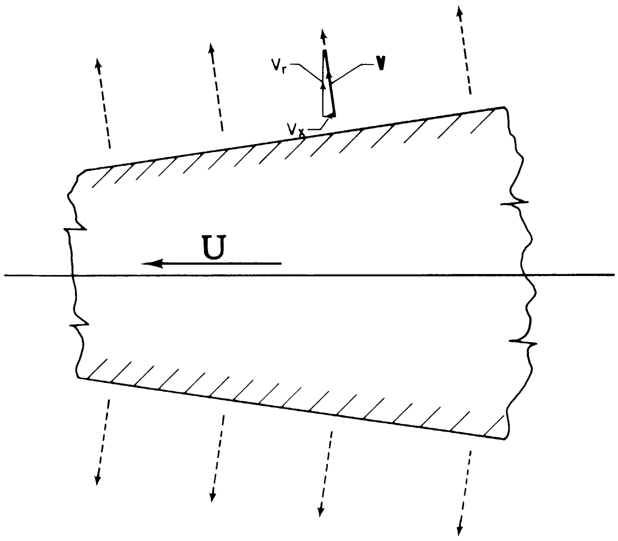

FIGURE 2 Close-Up View of Body and Fluid

is assumed to be inviscid, it can slip with respect to the body surface, and so its motion occurs almost entirely in the transverse direction. The forward speed U is rather large, and the fluid velocity **v** is quite small in comparison. Furthermore the component of **v** along the x axis, say v_x, is much smaller than the magnitude of **v** itself. Thus, the velocity components in this nearby region can be arranged in a hierarchy:

i) body speed, U;
ii) magnitude of fluid velocity, **v**;
iii) longitudinal component of **v**, i.e., v_x.

Each is much larger than the next. If ε is a measure of the ratio *beam/length* of the body, one might expect that $v_x/\mathbf{v}$ and $\mathbf{v}/U$ are comparable to ε in magnitude. Note that **v** is almost equal to the transverse component of velocity, say v_r, in magnitude.

3) For a sufficiently slender body, there is an intermediate viewpoint in which it is evident that the disturbance originates from a region of finite length along the x axis, although details of the body shape are not recognizable. One might suppose, from this viewpoint, that the disturbance actually arises from some singular behavior on the x axis, as suggested in Figure 3, where L is the body length.

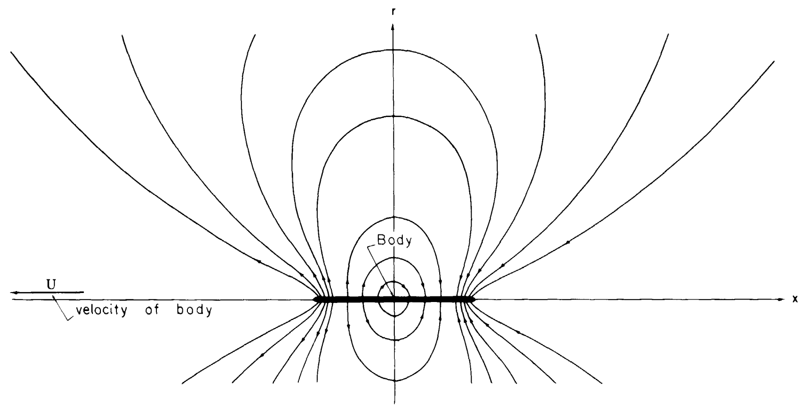

FIGURE 3 Moderately Far-Away View of Streamlines Due to Body Moving Steadily to Left

The first of these three viewpoints is hardly useful (it can be included in the third), but the other two definitely are, especially when they are properly interpreted as complementary views of the same phenomenon. In Figure 3, at moderate distance from the disturbance, the flow is distinctly three-dimensional, but, if we look very near the axis, where the disturbance originates, the flow appears to be almost two-dimensional, that is, entirely in the transverse planes. In Figure 2, the flow everywhere is apparently nearly two-dimensional; nearby, it depends on all of the detail of the body shape, but far away one may expect that much of the detail has no effect. We have here a tremendous simplification: The details of the body shape need to be considered only in the relatively simple two-dimensional problems corresponding to Figure 2; three-dimensional effects are not ignored, however, but they are considered only in the context of Figure 3, where the details of the body shape are not critical.

The basic problem of slender-body theory in aerodynamics is to solve the "near-field" problem of Figure 2 and to ensure that that solution is consistent with the viewpoint of Figure 3, the latter generally being called the "far-field" solution. Standard techniques exist for doing this; see, for example, Ogilvie (1970) for a discussion of techniques and for further references.

The worst trouble usually arises near the body ends, where the basic assumption is invalid, and much of slender-body theory is concerned with fixing up the theory in this respect. Such difficulties are fairly well understood in the problems of aerodynamics.

The applicability of slender-body theory to bodies of ship shape can be seen in Figure 4. This figure is adapted from Huang & Von Kerczek (1972). It shows the body plan of the underwater part of a Series 60 ($C_B = 0.60$) hull, superposed on which are the streamlines calculated under the condition that the free surface is replaced by a rigid wall. (The same streamlines would be obtained if a double body were constructed by adding to the hull its mirror image with respect to the undisturbed free surface, then tested in a wind tunnel.) The streamlines here have the appearance that would be seen by an observer moving with the ship in steady motion, that is, there is an apparent streaming flow past the hull. The slender-body-theory calculations are compared with "exact" calculations based on a genuine three-dimensional method of solution. The agreement is certainly not perfect, but the way in which the streamlines curl around the bilge and then come back up near the stern is rather faithfully predicted by the slender-body theory.

Formal Development of Slender-Ship Theory. These ideas can be introduced into ship hydrodynamics problems in a straightforward way. There are extra conditions to be satisfied at the location of the free surface, but the basic assumptions can be applied formally to simplify the extra conditions.

In the far field of the ship problem, corresponding to Figure 3 for the aerodynamic problem, the solution will indicate the existence of a typical ship wave system behind the ship, but the precise size and location of the waves cannot be found from the solution of the far-field problem alone, since the nature of the disturbance is only vaguely described in the far field. In the

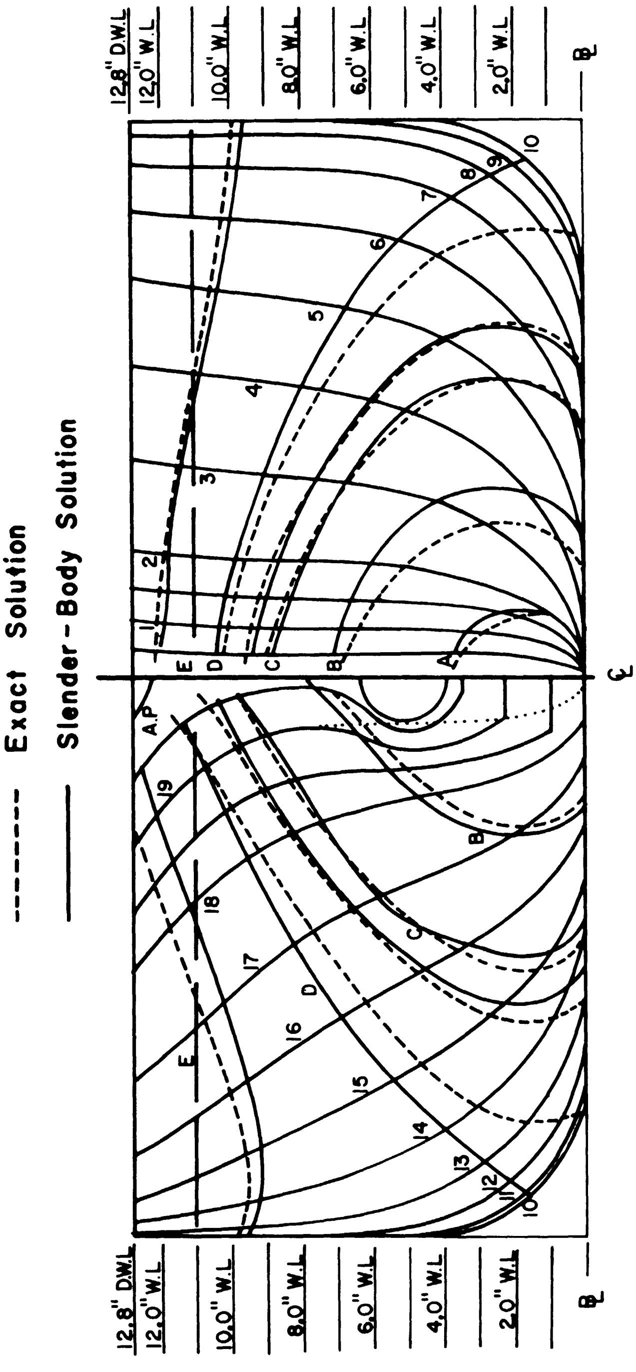

FIGURE 4 Streamlines on Ship Hull, Computed Two Ways

neighborhood of the line from which the disturbance appears to originate, the far-field solution degenerates into two simple parts, one representing a transverse wave, just like that seen directly downstream far behind the ship, the second representing an apparently two-dimensional flow in the transverse cross-sections. The latter contains some unknown parameters, which must be determined in such a way that the solution matches with the corresponding near-field solution. In the near field, the theory indicates that the free surface acts effectively like a rigid wall, and so the fluid motion ought to be approximately the same as in one half of the double-body problem described previously, e.g., as in Figure 4. The motion is practically two-dimensional (except for the steady stream moving past), and it can be predicted readily from the body shape by standard methods of fluid mechanics. When this has been done, the information previously lacking in the far field becomes available, that is, the precise nature of the disturbance will have been determined, from which the wave pattern can be described accurately.

This procedure yields some results that are qualitatively interesting, but from a quantitative point of view they are grossly invalid. Figure 5 shows one way in which the disparity between this theory and experiments is too great: The solid curve in the figure shows a prediction of wave shape alongside a ship model, and the points represent the same quantity as obtained from actual observation in the towing tank. The actual wave is only about half of what is predicted. If such an error also exists in the far-field waves, the wave resistance predicted will be about four times the true value. In fact, this theory actually predicts an *infinite* wave resistance for this hull form!

In Figure 5, the broken line shows the predicted dynamic pressure on the hull along the plane of symmetry in the corresponding double-body problem.

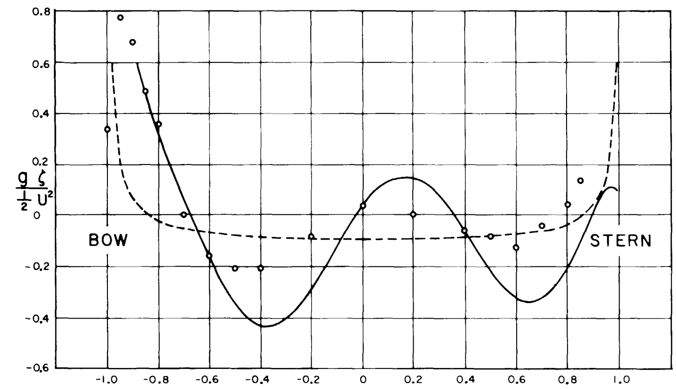

FIGURE 5 Computed Wave Profile Compared with Experimental Results
Broken line represents dynamic pressure on
double body in infinite fluid

In the nondimensional representation used here, the true pressure curve rises to the value unity at the body ends, and the slender-body-theory value rises to infinity. On the scale of this figure, one cannot distinguish between two such curves, since they both go off scale near the ends. One is apt to slough off this disagreement with the observation that slender-body theory never gives good predictions near the ends of a body anyway. Unfortunately, in the ship problem, any singular behavior at the free surface may lead to completely untenable results. That is what happens here. The predicted infinite value of wave resistance is the most obvious manifestation.

Thus it appears that the formal application of slender-body theory to the ship problem leads to some results that are completely invalid, even though one can compute some other quantities that do not appear to be outrageous in their behavior. Part of the trouble is due to "end effects," the original demon in slender-body theory, and part is due to the formal transfer from aerodynamics of certain assumptions that do not remain valid in the ship problem.

Modified Slender-Ship Theory. When a body moves through an unbounded fluid, there is just about as much disturbance ahead of the body as behind it. This is suggested in the sketch of Figure 1, which is symmetrical fore and aft. But, in the presence of a free surface, this is not true at all. Everyone has observed the characteristic wave pattern caused by a moving ship, in which the fluid motion is practically negligible outside of a wedge-shaped region behind the ship. The water ahead of the bow is not set into motion until the bow is extremely close, at which time the water is suddenly accelerated so that it can pass around the advancing ship.

In a small region around the ship bow, the fluid motion is determined primarily by i) the hull geometry near the bow, ii) the inertial characteristics of the water, and iii) the constant-pressure property of the free surface. Gravity has little effect locally. This picture is incompatible with the formal slender-ship theory described previously. There, as I pointed out, the free surface acts very much like a rigid wall in the near field, which can happen only if gravity somehow dominates the picture near the body.

In order to modify the formal theory so that the bow flow would be more accurately described, it has been necessary to change the basic assumptions concerning relative rates of change in longitudinal and transverse directions. Ogilvie (1972) showed one way of doing this so that the near-field flow is still primarily two-dimensional (just as in ordinary slender-body theory), while the longitudinal rate of change is increased enough so that a realistic description of the flow around a ship bow can be obtained.

One simple case was worked out analytically and checked experimentally. It turned out that, for a simple wedge-shaped bow, the entire problem could be made nondimensional and a single universal curve could be obtained for the shape of the bow wave along the side of the wedge. This curve is shown in Figure 6. A photograph of the bow wave in a typical test is shown in Figure 7. Several dozen such tests were made with two wedge angles, a variety of drafts, and several speeds. The results show fairly good agreement with predictions, as reported by Ogilvie (1972).

In Figure 6, the predicted wave shape behaves like 2/X for large X, where X is a nondimensional coordinate measured downstream from the wedge apex. The curve corresponding to 2/X has been extended down to small values of X by the broken line. The latter represents precisely the wave shape that is predicted by the formal slender-ship theory, as shown in Figure 5. Thus the infinite wave height predicted so erroneously by the earlier theory has been removed in this new analysis, and it is reasonable to expect that the infinite wave resistance predicted previously will have been eliminated too, although the analysis is not yet complete in that respect.

Obtaining the complete solution for ships of arbitrary form is not so easy now as it was in the earlier slender-ship theory, but computer programs are being produced for this purpose. The case of the thin wedge was studied first because it was the single obvious case in which a solution could be obtained very easily, and so it was an ideal case to be worked out for initial verification in the experiments. However, the theory is in no way limited to thin bodies, and so the completed computer programs should be useful in predicting the flow around ships which are not adequately represented by, say, the classical "thin-ship" representation.

Besides the special case of the thin wedge, another case has been worked out in some detail, namely, the "flat ship." This is described in a recent report by Tuck (1973). Other cases are also being investigated, including a surface-effect ship (two hulls separated by a region on which a pressure field is applied) and an asymmetrical ship (which is approximately equivalent to a ship in a steady turn).

Motions of a Slender Ship. Ten years ago, the formal slender-body theory was applied to problems of oscillating ships and of ships in ambient waves. The theory was generally as sterile as in the steady-motion problem. It turned out again that the free-surface condition in the near field was replaced by a rigid-wall condition. A consequence is that wave damping and added-mass effects are very difficult to determine, if indeed the theory gives such effects at all. The complete computations have never been completely carried out.

Still, most ships *are* slender, and one may expect to be able to take advantage of this fact in deriving a theory which is less complicated than a full, accurate, and impossibly complicated three-dimensional theory. In effect, this had already been done almost twenty years ago by Professor B. V. Korvin-Kroukovsky at Stevens Institute of Technology. He used a straightforward

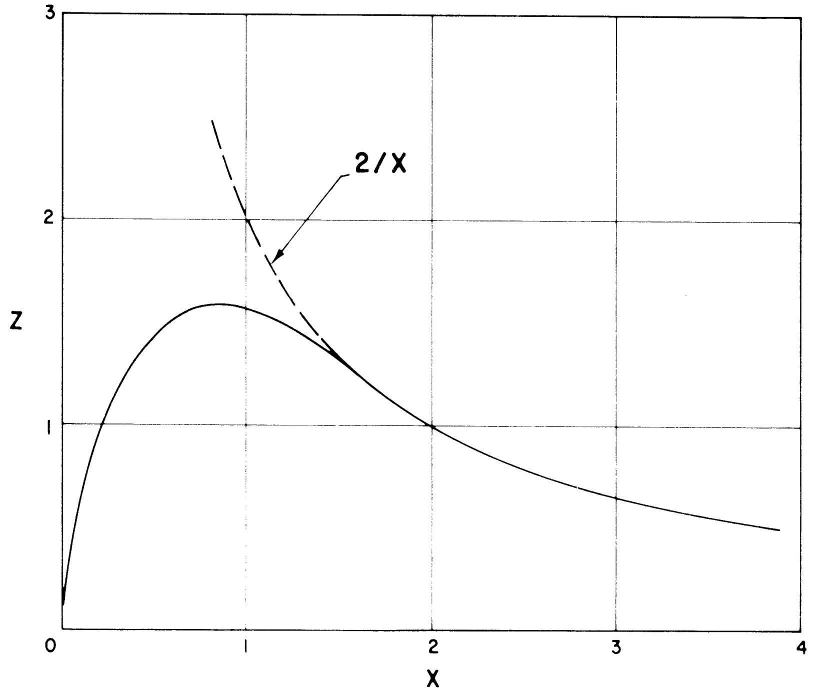

FIGURE 6 Predicted Bow-Wave Shape on Symmetrical Wedge

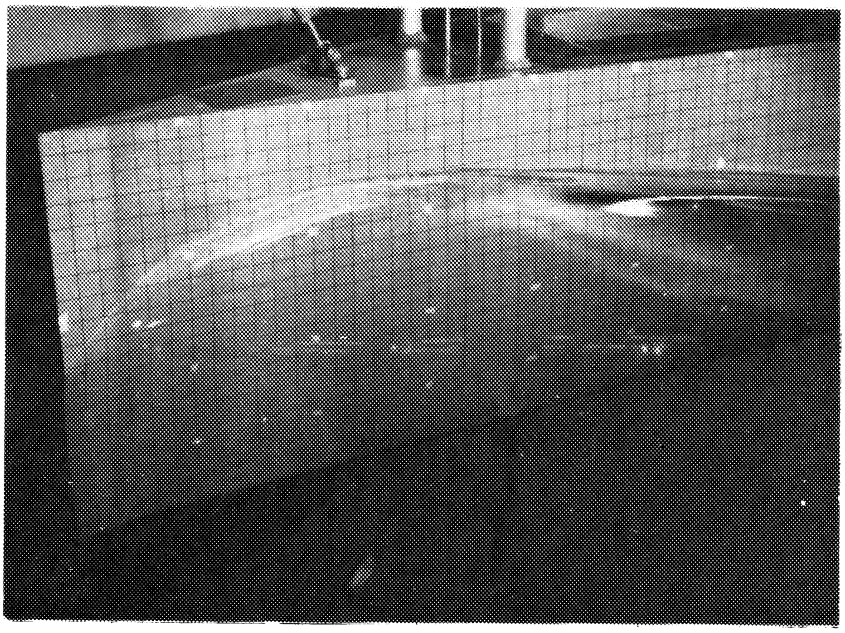

FIGURE 7 Bow Wave on a Wedge from a Typical Test

physical argument in much the same spirit as Munk's original work on airships, and he obtained what has come to be called the "strip theory" of ship motions. The most notable accomplishment of his investigation was that the boundary-value problems to be solved were all two-dimensional, just as in slender-body theory. However, he did not use formal perturbation schemes in setting up his problem, and so he did not become locked in with the rigid-wall condition in place of a proper free-surface condition.

It was not until 1969 that the connection between Professor Korvin-Kroukovsky's strip theory and slender-body theory was adequately enunciated. Ogilvie & Tuck (1969) showed that strip theory is a special case of slender-body theory if, in the latter, one assumes that all surface waves in the problem are of moderate length compared with the ship beam. The previously mentioned formal slender-body theory carried an implication that all waves are so long that they cannot be detected directly on a scale of measurement appropriate to the scale for the ship beam and draft. That implication was really an extra assumption beyond the basic set of assumptions of aerodynamic slender-body theory, but it was not generally recognized ten years ago that it was a rather stringent additional condition which could specialize the resulting slender-body theory to the extent that useful results could no longer be obtained. What has generally been called the "slender-body theory" of ship motions is thus a *special case* of slender-body theory; Professor Korvin-Kroukovsky's strip theory is essentially another special case.

The results of systematically developing the slender-ship theory of ship motions have not been drastically different from what was already known from strip theory. However, some results obtained by Faltinsen (1971) could not possibly have been derived by the heuristic approach. One particular predic-

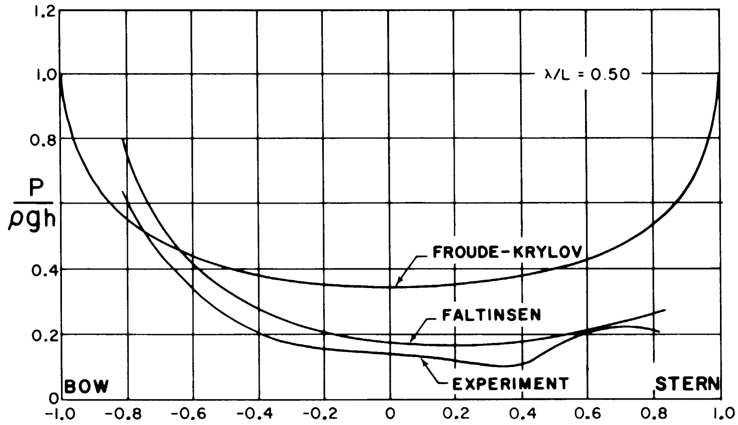

FIGURE 8 Pressure Amplitude in Wave Moving Along a Spheroid
Calculations and measurements made along a
line nearly parallel to the keel

tion of his is worth noting, and it is shown in Figure 8. The amplitude of the pressure oscillation on the surface of a spheroid in head waves is shown. For the case represented here, the waves have a length equal to half the body length; the data are all given along a line drawn on the body close to the keel line. The curve marked "Froude-Krylov" shows what the pressure amplitude would be along this line if the body were not present. Faltinsen's theory is also indicated, along with experimental data points taken in the towing tank at the University of California at Berkeley, kindly provided to us by Dr. Choung Mook Lee. The amplitude of the wave is apparently reduced steadily along the length of the body because of the presence of the body, and Faltinsen's predictions show this fairly well. His predictions are quite erroneous at the bow, as so frequently happens in slender-body theory. Nevertheless, the longitudinal decay of amplitude had never before been predicted theoretically except in a very qualitative way, and so this figure represents a real accomplishment of slender-body theory. The prediction is important in the design of very large ships, in which rather short waves may cause large bending moments, even though the resulting motions are not important.

Continuing Studies in Slender-Body Theory. Several aspects of ship hydrodynamics are being further investigated by means of slender-body theory in the research program of the Department of Naval Architecture and Marine Engineering of The University of Michigan. The importance of the bow wave in ship turning has already been studied in a dissertation by Hirata (1972). Further studies of maneuvering problems are continuing. The motion of a ship in shallow water has also been studied intensively, largely by Dr. Ernest O. Tuck (The University of Adelaide, Australia), who was Visiting Professor of Fluid Mechanics in the Department in 1972–73; his work has been extended by Professor Robert F. Beck, under whose direction experiments have been conducted for the determination of the range of validity of the shallow-water theory. In the near future, several problems will be studied both theoretically and experimentally in connection with the maneuvering and control of deep-draft ships in restricted waterways.

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REFERENCES

Faltinsen, Odd M., "A Rational Strip Theory for Ship Motions: Part II," Report No. 113, Department of Naval Architecture and Marine Engineering, The University of Michigan (1971).

Hirata, Miguel H., "On the Steady Turn of a Ship," Report No. 134, Dept. of Nav. Arch. & Mar. Eng., The University of Michigan (1972).

Huang, T. T., & Von Kerczek, C. H., "Shear Stress and Pressure Distribution on a Surface Ship Model: Theory and Experiment," *Ninth Symposium on Naval Hydrodynamics* (1972) (in press).

Munk, Max M., "The Aerodynamic Forces on Airship Hulls," Report No. 184, Nat. Adv. Comm. Aero. (1924).

Ogilvie, T. Francis, "Singular Perturbation Problems in Ship Hydrodynamics," *Eighth Symposium on Naval Hydrodynamics*, ACR-179 (1970) 661-806, Office of Naval Research, Washington, D.C. (Also: Report No. 096, Dept. of Nav. Arch. & Mar. Eng., The University of Michigan.)

Ogilvie, T. Francis, "The Wave Generated by a Fine Ship Bow," Report No. 127, Dept. of Nav. Arch. & Mar. Eng., The University of Michigan (1973). (Also to appear in: *Ninth Symposium on Naval Hydrodynamics.*)

Ogilvie, T. Francis, & Tuck, Ernest O., "A Rational Strip Theory for Ship Motions: Part I," Report No. 013, Dept. of Nav. Arch. & Mar. Eng., The University of Michigan (1971).

Tuck, E. O., "Low-Aspect-Ratio Flat-Ship Theory," Report No. 144, Dept. of Nav. Arch. & Mar. Eng., The University of Michigan (1973).

Capsizing of Deck-Loaded Barges in Irregular Beam Seas

Eric D. Snyder

Introduction. Deck cargo barges are required by the United States Coast Guard to meet a dynamic stability requirement of 15 foot-degrees of area under the righting-arm curve up to the maximum righting arm. This criterion was established by Rahola in 1939 in his doctoral thesis.[1] He arrived at this criterion after doing a statistical study of vessel casualties. However, the vessels he studied were self-propelled displacement forms, and his findings may not apply to deck cargo barges with their high beam/depth ratios and low freeboard.

Because of their geometry, deck cargo barges must be loaded so that their metacentric height (GM) is fairly large, in order to meet the dynamic stability criterion. This in turn leads to short periods of roll and high angular accelerations. These high angular accelerations can cause shifting or loss of cargo from the breaking of cargo lashings. If the dynamic stability criterion could be lowered, the roll motions would be eased. This is desirable if the vessel could still sail safely.

Under authorization from the United States Coast Guard, The University of Michigan undertook an experimental program to investigate the dynamic stability needed by deck cargo barges to resist capsizing in irregular beam seas. Although some tests were conducted to investigate the effects of various deck cargoes, for the most part the tests were conducted on a model with a flush deck, i.e., no cargo, but with loading to simulate the center of gravity of a vessel with deck cargo. This article concentrates on the tests conducted on the flush-decked model. Further information can be found in the two reports issued to the Coast Guard.[2,3]

Test Program. Because of the great variety in deck-cargo-barge hull forms and the large number of loading conditions which might be investigated, the test program was of necessity limited in scope. One hull form representative of current design practice on the northwest coast of the United States was selected as the test model. The behavior of the model to irregular beam seas was investigated at several different loading conditions. The loading condition was given by displacement (Δ), represented by the draft/depth ratio (T/D) and the vertical center of gravity location (KG). For a given hull form, these two parameters uniquely determine the dynamic stability (D.S.). The lines of the test model are shown in Figure 1, and its geometric particulars are given in Table 1. The various loading conditions for the tests are given in Table 2.

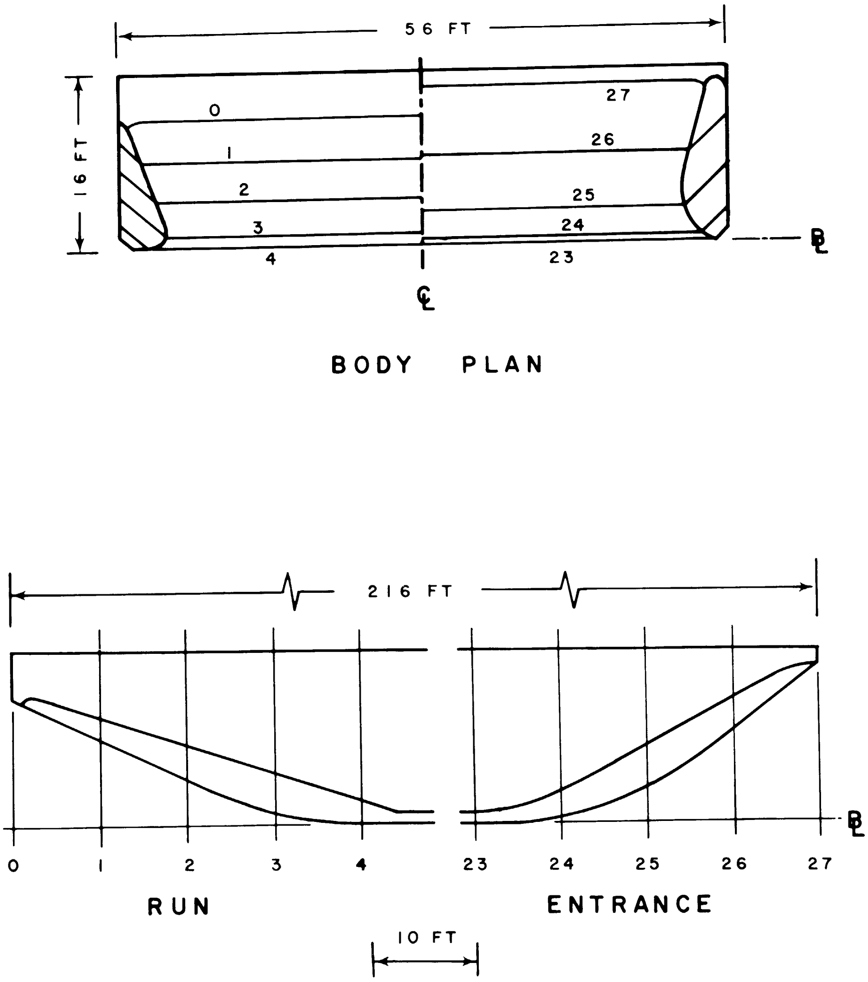

FIGURE 1 Ship Lines

TABLE 1
Model and Ship Geometric Particulars

Ship Type: Deck Cargo Barge

	Phase I Model	Phase II Model	Ship
Scale Ratio:	λ = 32.	λ = 42.	
LOA	6.750 ft	5.143 ft	216.00 ft
B	1.750 ft	1.333 ft	56.00 ft
D	0.500 ft	0.381 ft	16.00 ft
T/D = 0.70:			
LWL	6.598 ft	5.027 ft	211.13 ft
∇	3.618 ft^3	1.600 ft^3	118,541. ft^3
Δ	225.3 lbs	99.6 lbs	3,387. LTSW
T/D = 0.75:			
LWL	6.650 ft	5.067 ft	212.80 ft
∇	3.906 ft^3	1.728 ft^3	128,008. ft^3
Δ	243.2 lbs	107.6 lbs	3,657. LTSW
T/D = 0.80:			
LWL	6.682 ft	5.091 ft	213.82 ft
∇	4.194 ft^3	1.855 ft^3	137,433. ft^3
Δ	261.2 lbs	115.5 lbs	3,927. LTSW
T/D = 0.90:			
LWL	6.750 ft	5.143 ft	216.00 ft
∇	4.789 ft^3	2.118 ft^3	156,918. ft^3
Δ	298.2 lbs	131.9 lbs	4,483. LTSW

NOTE: Model displacements are in fresh water at 70°F.

TABLE 2
Test Conditions

Phase	Cond. No.	T/D	D.S. (ft deg)	KG (ft)	GM (ft)	K/B
Phase I	A	0.70	4.00	28.51	3.03	0.50
	B	0.70	6.00	27.01	4.53	
	C	0.70	8.00	25.84	5.70	
	D	0.70	10.00	24.75	6.79	0.40
	E	0.75	5.00	24.72	5.32	
	F	0.75	5.50	24.32	5.72	
	G	0.75	5.75	24.13	5.91	0.37
	H	0.75	6.00	23.95	6.09	
	J	0.75	7.50	23.01	7.03	
	K	0.75	10.00	21.60	8.44	0.37
	L	0.75	12.50	20.53	9.51	0.34
Phase II	1	0.70	3.95	28.56	2.98	0.421
	2	0.70	5.95	27.07	4.47	0.408
	3	0.70	8.20	25.67	5.87	0.396
	4	0.90	4.15	16.65	10.44	0.389
	5	0.90	6.45	14.44	12.65	0.349
	6	0.90	4.95	15.79	11.30	0.364
	7	0.80	3.87	22.73	6.25	0.430
	8	0.80	5.88	20.88	8.10	0.397
	9	0.80	8.00	19.43	9.55	0.384

NOTES:
Dimensions are for the full scale barge.
K = Roll radius of gyration. Measured in air.

Testing took place in two phases. In Phase I, a wide range of dynamic stability was investigated for two T/D ratios. The purpose was to gain a preliminary, general understanding of the problem. Phase II concentrated on a narrower range of dynamic stability, but more T/D ratios were investigated within this range. In Phase II, the range of test conditions was selected after an analysis of the data from the Phase I testing.

In both phases of testing, the test procedure was essentially the same. The model was placed across the towing tank and restrained from drifting by two light spring lines attached to the bow and the stern on the centerline. The model was then subjected to irregular beam seas and the time history of the incident wave train was measured. These records were later analyzed by a real-time spectrum analyzer (SAICOR Model 24) to yield their spectral density curves. From the spectral density curves, the significant wave height could be determined by the following formula:

$$\zeta_{1/3} = 4.0 \sqrt{m_0} ,$$

where

$\zeta_{1/3}$ = significant wave height, and
m_0 = area under the spectral density curve.

In Phase I, the model was judged safe from capsizing if it survived in the irregular sea for about 15 minutes ship time. In Phase II, the model was required to survive nearly 22 minutes ship time.

The primary purpose of this project was to determine the amount of dynamic stability needed by deck cargo barges to resist capsizing. Therefore, at each test condition the model was subjected to larger and larger significant-height waves until it capsized, if this were possible within the capabilites of the wavemaker.

The irregular waves generated during this test program had spectral density curves derived from recommendations of the Seakeeping Committee of the 12th International Towing Tank Conference.[4] The formula for this spectrum is

$$S(\omega) = \frac{173\ \zeta_{1/3}^2}{T_1^4\ \omega^5}\ exp\ (-\ 691/T_1^4\omega^4)\ ,$$

where

$S(\omega)$ = spectral density,
T_1 = characteristic period,
$\zeta_{1/3}$ = significant wave height,
ω = radian frequency.

These spectral density curves depend upon two parameters, the significant wave height and the characteristic period of the random wave. For purposes of this test program, the characteristic period was kept constant during each phase of testing and only the significant wave height varied. Generally speaking, this meant that the shape of the wave spectrum remained constant during each phase of testing but the size or scale of the wave spectrum changed. For Phase I, the characteristic period of the wave spectrum was 9.8 seconds ship scale, and for Phase II the characteristic period was 10.0 seconds ship scale.

There were, however, some differences in the nature of the test program between Phase I and Phase II. A smaller model was used in Phase II. This was done in hopes of achieving larger waves relative to the model size. Also, the method of generating irregular waves was different in the two phases of the program. In Phase I, an irregular wave with the desired spectral density was generated by adding together twelve sine waves of distinct frequency and appropriate amplitude, with random phase. Thus the waves generated during Phase I were not truly random. In Phase II, more nearly random waves were generated by applying digital filtering techniques to a string of Gaussian distributed random numbers. This procedure was done "off line" and

TABLE 3
Results: Measured Significant Wave Height in Ship Feet

T/D = 0.70							
D.S. (ft deg)	4.00	6.00	8.00	10.00	3.95	5.95	8.20
Cond. No.	A	B	C	D	1	2	3
	20.3	22.5	20.8	25.8	17.69*	13.93	16.87
	21.6	23.5	24.3		18.92	17.96	17.02
	25.6	26.0	25.3		23.02	18.48*	19.16*
	26.4				23.46*	19.06*	21.80*
					23.60*	20.80*	24.28*
						20.83*	
						22.22*	

T/D = 0.75							
D.S. (ft deg)	5.00	5.50	5.75	6.00	7.50	10.00	12.50
Cond. No.	E	F	G	H	J	K	L
	25.3 *	25.4*	15.1	23.67	17.2	16.7	19.7
	31.78		21.78		17.7	22.2	23.2
			23.3		22.6	25.0	28.0
			24.3		22.8	26.7	30.1
			26.3		27.8		
			26.6				

T/D = 0.80			
D.S. (ft deg)	3.87	5.88	8.00
Cond No.	7	8	9
	16.30*	17.46	18.23*
	17.37	17.52*	19.47
	19.71	19.05*	21.05
	19.95*		
	22.11*		
	22.69*		

T/D = 0.90			
D.S. (ft deg)	4.15	4.95	6.45
Cond No.	4	6	5
	15.85*	24.07	13.23
	17.00	28.29*	21.42
	19.15*		24.31
	19.59*		
	19.95*		

* Indicates that the model capsized.

resulted in a magnetic tape containing a random voltage signal, which provided the input to the wavemaker, yielding the desired irregular wave. Because the input tape was prepared digitally, only discrete frequencies appear in the final wave. In this respect the wave was similar to that used in Phase I. However, in Phase II, 512 frequencies were combined to form the irregular wave rather than twelve.

Results. The principal objective in this program was to determine how large a wave would capsize the test model, as a function of loading, expressed in terms of both displacement and dynamic stability. Unfortunately, the results of the tests do not indicate that there is a "capsize threshold." Rather, only broad general trends are indicated. The results are given in Table 3 and shown graphically in Figure 2.

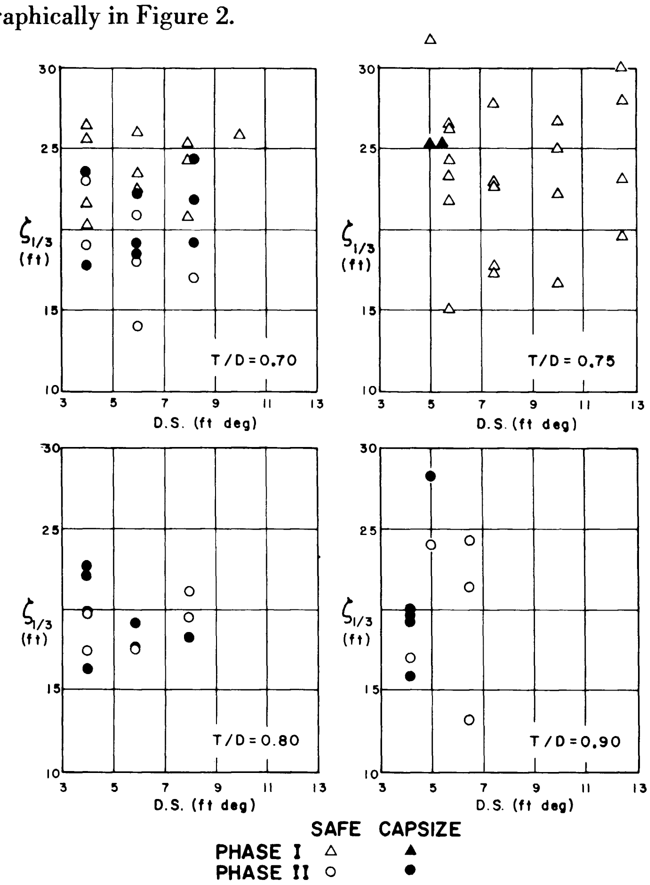

FIGURE 2 Significant Wave Height vs Dynamic Stability

Intuitively, one would expect a relatively small wave to be sufficient to capsize the model if the dynamic stability is small and if the displacement is large (so that the freeboard is small). This, however, is indicated only generally by the data. It does appear that a larger amount of dynamic stability and increased freeboard improves the vessel's survivability, but there is no evidence of a critical amount of dynamic stability which could serve as a stablity criterion. This may be due to the random nature of the incident wave.

Presumably, there is some finite set of conditions which must necessarily be met to cause a vessel at a given loading to capsize. In random waves, these necessary conditions occur probabilistically and to a certain extent independently of the significant height of the wave. Thus the conditions necessary for capsizing can occur in two separate waves of different significant height. To be sure, these conditions probably depend upon the size and/or steepness of the wave, and the likelihood of encountering these conditions increases with increasing significant wave height. Thus the likelihood of capsizing increases with increased signficant wave height, but there can not be a precisely defined threshold. Until more is known about the exact nonlinear nature of capsizing, it is impossible to predict whether a given vessel at a given loading will capsize in a given seaway.

Also, the "random" occurrence of the necessary conditions for capsizing accounts for some of the scatter in the data. In particular, it explains why the model at some test conditions capsized in one wave when it appeared to be safe in another wave of larger significant height.

The results of the Phase II tests do not tend to verify the results of the Phase I tests. That is, at the same loading condition, the model in Phase I seemed to survive waves as large as those which capsized the model in Phase II. This could be due to any one or a combination of several factors which differed between the two phases: 1) the model sizes were different and scale effects could be important, 2) the waves used in Phase II were more nearly random than those used in Phase I, with a resulting increase in the likelihood of capsizing conditions, and 3) each test run in Phase II was of longer duration than in Phase I.

Discussion. This article has dealt with one aspect of a testing program conducted at The University of Michigan for the investigation of the dynamic stability needed by deck cargo barges to resist capsizing in irregular beam seas. Although the matrix of loading conditions with a flush-deck model formed the major portion of the testing program, two other aspects affecting the survivability of deck cargo barges were investigated briefly. These were 1) the effect of cargo on deck and 2) the effect of the characteristic period of the spectral density of the incident waves. The data are insufficient to afford definite conclusions, but they do indicate that these two aspects are important.

Two types of deck cargo were simulated. One was solid, which provided added buoyancy when immersed and did not trap water on deck. The other was porous, which did not provide buoyancy when immersed but did allow water to be trapped on deck. Of these two types of cargo, the second did not appear to affect survivability significantly, in comparison with the flush-deck case, while the first did markedly improve survivability. This tends to verify the earlier conclusion as to the importance of freeboard on the survivability of the model.

The inverse of the characteristic period of the spectral density of the incident wave roughly indicates the frequency about which most of the energy in the wave is concentrated. If the natural frequency of the vessel in roll is close to this frequency, one would expect the vessel to capsize in smaller waves. The vessel is essentially being excited at or near its resonance frequency. Our test results do indicate that this is the case and the relation between the characteristic frequency of the spectral density of the incident wave and the natural roll frequency is an important parameter in determining the survivability of a deck cargo barge.

The test program described here was of limited scope, and it could not be expected to answer all of the questions about the ability of a deck-cargo barge to resist capsizing. However, some areas of fruitful further research have been found. Among these would be a more extensive investigation of the effects of cargo on deck, as well as the effects of the wave spectral density (i.e., exciting moment) on the vessel response. Another item of importance is the dynamic effect of water on deck. During the tests with the flush-deck model, water came on deck often from deck edge immersion, regardless of whether capsizing occurred. The dynamics of this water on deck must have an important effect on the subsequent motions of the vessel. Also, since these tests were all performed in beam seas with zero forward speed, an investigation of the effects of heading relative to the incident wave and the effects of forward speed is needed.

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REFERENCES

1. Rahola, Jaakko, "The Judging of the Stability of Ships and the Determination of the Minimum Amount of Stability," doctoral thesis, Helsinki, 1939.

2. Young, Bernard J., "The Behavior of a Deck Cargo Barge in Extreme Beam

Seas," University of Michigan report 010112-2, submitted to United States Coast Guard, March 1972.

3. Snyder, Eric D., "An Investigation of Deck Cargo Barge Stability in Extreme Irregular Beam Seas," University of Michigan report 010112-3, submitted to United States Coast Guard, August 1973.

4. Proceedings of the 12th International Towing Tank Conference, Rome, 1969.

Rational Selection of the Power Service Margin

Peter M. Swift

The Service Margin. The service margin is an allowance for the difference in the power requirements of a ship between its trial and average service conditions. In the trial condition, the new ship operates in calm water, fair weather, and with a clean exterior hull. In the service condition the power required to maintain the same speed is inevitably higher because of less favorable average sea and weather conditions and because of deterioration effects, as illustrated in Figure 1. The service margin therefore takes account of environmental factors such as sea state, wind, and current, and of deterioration effects, which include hull fouling and corrosion, machinery wear, etc.

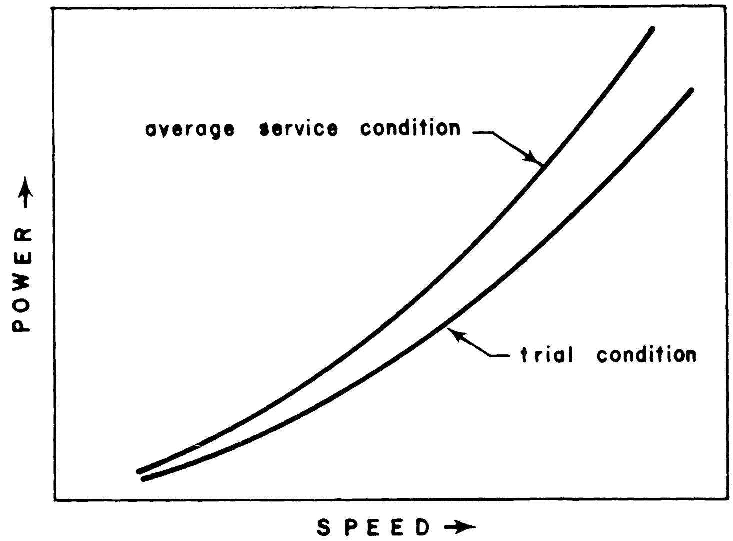


FIGURE 1 Power-Speed relationships, for trial and average service conditions

Selection of the Service Margin. Traditionally the service margin has been selected through the provision of a fixed power margin or of a speed margin: With the speed margin, a trial speed in excess of the design service speed is selected and the required power is determined for the trial speed in the trial condition. Figure 2 illustrates the speed margin approach. This approach has been used at various times in parts of Europe, as has the power margin method.

The alternative to a speed margin is the selection of the service margin the adoption of a fixed power margin, such as the 25% required by the U.S. Maritime Administration, which stipulates that design speed be reached on

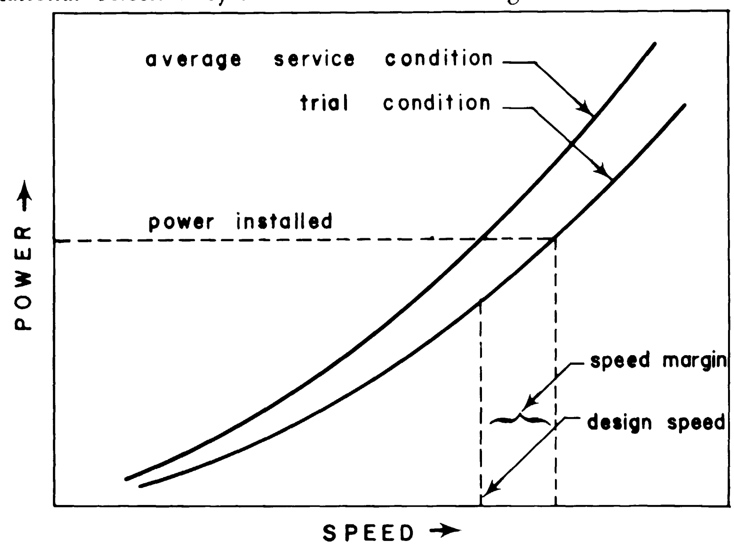


FIGURE 2 Power-Speed relationships, illustrating speed margins

trials at 80% of normal power. Figure 3 illustrates this approach, which is commonly used in North America.

In both methods the trial condition is used as the accepted reference, since it is well defined and experimentally verifiable, while the average service condition is not.

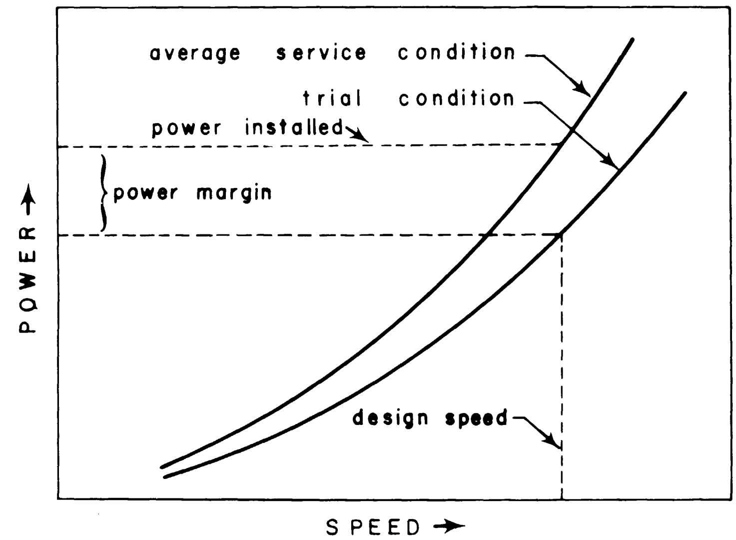


FIGURE 3 Power-Speed relationships, illustrating power margin

Proposed Approach. It is proposed that, rather than considering the ship design speed as a free variable, or prespecified requirement, and calculating the required installed horsepower, the designer treat the installed horsepower as an independent design variable. A stipulated minimum service speed to meet ship scheduling requirements may then be handled as an inequality constraint that has to be satisfied in the ship design.

For a given installed horsepower, it is necesary to determine the long-term average service speed, which requires realistically modelling the operational environment and the characteristics of the vessel. This requires an analysis of ship performance in the various seaways to be encountered and a study of hull deterioration effects.

Once the long-term average service speed has been determined, the calm water power required for this service speed in the trial condition is computed, leading to the definition of an "effective service margin" as:

$$\text{"effective service margin"} = \left\{ \frac{\text{installed horsepower}}{\text{calm water power for average service speed}} - 1 \right\} \times 100\%.$$

Environmental Analysis and Ship Performance. In a separate project in cooperation with the Massachusetts Institute of Technology (Ref. 1), seastate data for the North and South Atlantic, the Indian Ocean, and the Persian Gulf were programmed from Hogben and Lumb's "Ocean Wave Statistics" (Ref. 2). This reference contains the data necessary to compute the probabilities of the energy density spectra for specific seastates in each area, season, and direction for the major shipping routes of the world. The data were collected over an eight-year period and represent several million wave observations by ocean weather ships and participating merchant ships. The data were analyzed by Hogben and Lumb in such a way that values of the significant wave height, $H_{1\text{-}3}$, and the frequency of the spectral peak, ω_p, were obtained from the observed values of H and T given in their tables:

$$H_{1/3} = 1.23 + 0.88 \text{ H meters},$$
$$T_p = T_0 = 4.10 + 0.76 \text{ T seconds},$$
$$\omega_p = 2\pi/T_p \,,$$

where H is the average observed wave height, in meters, reported by the ocean weather ships, T_0 is the modal period, and T is the observed wave period reported by these ships.

Ship responses to specific seaways have been computed by interfacing the data obtained from the above with seakeeping tables of Loukakis & Chryssostomidis (Ref. 3). They developed a "Seakeeping Standard Series" for Series

60 type hull forms over the following ranges of ship parameters:

$$C_B : 0.55\text{–}0.90 \ ,$$
$$L/B : 5.50\text{–}8.50 \ ,$$
$$B/T : 2.00\text{–}4.00 \ ,$$

for Froude numbers in the range 0.10–0.30 and nondimensional sea states from 0.015 to 0.100.

It has therefore been possible to predict the heave and pitch motions, the bending moment amidships, added resistance, vertical accelerations, relative motions, and relative velocities for a specific ship in a specific seaway. These responses have then been weighted by the respective spectrum probabilities calculated above.

For a specified route, the results are then further weighted by the percentage time spent in each of the areas covered by Hogben & Lumb's analysis, and they take into account the season, also on the basis of the data of Hogben & Lumb.

The calculated added drag in a seaway is added to the predicted hull deterioration effects in order to determine the average service speed. This service speed is calculated by means of established powering-speed relationships, such as provided by standard series, etc.

Hull deterioration. An extensive study of previously reported experiments for measuring hull deterioration effects on powering requirements has been undertaken. The purpose was to determine time-dependent relationships for fouling and corrosion effects for a variety of commercial ships on different trade routes. This is similar to work of Lackenby (Ref. 4) and others, who have reported the percentage increase in power with time, due to fouling and increasing plate roughness, necessary to maintain a constant service speed. An example for the cross-channel ferry *Koningen Elisabeth* is given in Figure 4, where the effects of drydocking and hull bottom scraping are clearly visible.

The results of this study have been incorporated into two examples, described below, and, because of some uncertainties in the degree of accuracy involved, sensitivity studies have been made on the assumed fouling and corrosion rates and their effects.

Examples. This approach to a more rational selection of the installed horsepower has been illustrated with two examples:

- an oil tanker operating from the Persian Gulf to the U.S. East Coast,
- a North Atlantic containership.

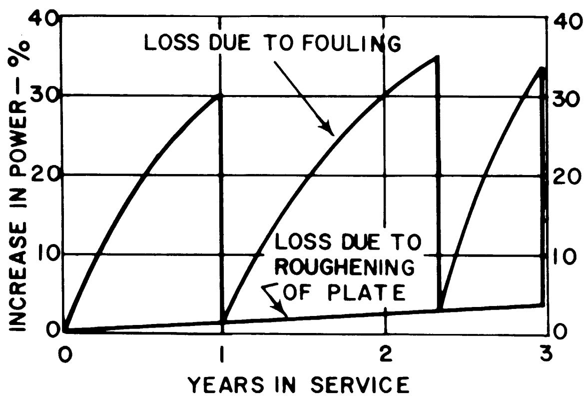


FIGURE 4 Loss in performance with time in service for the cross-channel ship *Koningen Elisabeth*

Ship design and construction, powering, and operating synthesis models have been developed for each case. These models have been run in optimization mode with the principal ship characteristics and the installed horsepower as design variables. Constraints are introduced to limit the characteristics to the range of validity of the design relationships and to model stability requirements and freeboard regulations. Operational constraints include motion sickness considerations with an upper limit on the acceleration at house locations. Cargo safety is accounted for also by considering the vertical acceleration and constraining the permitted average-1/10-highest values. Other operational constraints are deck wetness, which is expressed in terms of the amplitude of the forward stations exceeding the freeboard, and slamming, of which the permitted frequency of occurrence is limited. In the event of excessive ship slow-down, caused by the imposed operating constraints, the heading of the vessel is assumed to change temporarily.

The optimization method used is the External Penalty Function Technique; it is a slight modification of the program of Wangdahl (Ref. 5). It is designed for minimization problems and it uses a transformed objective function plus a penalty term. This penalty term is zero in the feasible regions of the decision space and becomes operative when one or more of the constraints is violated. This method, incorporated with a Hooke & Jeeves direct search, has been found to be both effective and efficient in this application.

Results. At this time, the approach appears to have been successfully validated. A detailed report, including results, will be published soon.

REFERENCES

1. Oakes, M., et al, "A Computer-Aided Method of Obtaining Seaway Statistics for an Arbitrary Shipping Route," to be published.

2. Hogben, N., & Lumb, F. E., "Ocean Wave Statistics," National Physical Laboratory, Her Majesty's Stationery Office, London, 1967.

3. Loukakis, T., & Chryssostimidis, C., "The Seakeeping Performance of an Extended Series 60," a report to the U.S. Maritime Administration, to be published.

4. Lackenby, H., "The Resistance of Ships, with Special Reference to Skin Friction and Hull Service Condition," *Proc. Inst. Mech. Eng.*, Vol. 176, 1962.

5. Wangdahl, G. E., "The External Penalty Function Optimization Technique and Its Application to Ship Design," Report No. 129, Department of Naval Architecture & Marine Engineering, The University of Michigan, 1972.

Arrangement of Shipboard Piping by Digital Computer

John B. Woodward III

Introducton. Arrangement of piping (often referred to synonymously as *layout*) is the task of choosing the coordinates of paths connecting terminals in some specified way. In its elementary form, arrangement consists of finding a single path between two terminals, in which case the process can be seen to follow rational but simple rules, the essence of which is

Choose the shortest path, consistent with the following constraints:

(1) Avoid all obstructing objects or spaces in which the pipe is not permitted (e.g., access space).

(2) Run close to structure at points where support is required.

These rules are close to being intuitively obvious, so much so that even the most inexperienced designer would produce a satisfactory arrangement in many instances when supplied with only a modicum of additional details.

In practice, many problems are encountered that require the application of additional rules. Some problems and their rules may be quite specific. For example, gravity drain piping must be arranged with a continuous slope of some minimum value, and the rule might be stated, "provide minimum slope of x inches/foot." Others are more nebulous. For example, where several piping systems are competing for limited space, the designer will aim for a best total array, but the definition of "best" is impossible to state categorically (least total length? least number of bends and elbows? least total weight?), and it is impossible to state rules that he follows in achieving the best arrangement.

Can the digital computer do what the human designer does? I have chosen to introduce the topic by a mention of rules, since this implies that an algorithm could be constructed for a computer to follow, thus duplicating the human's actions. Surely the computer can do this, but it suffers a grave handicap in that it cannot see. It is therefore found immediately that, when programming the designer's rules is attempted, they are more complex than they seem to a brain equipped with eyes. Instructions such as "follow shortest path" and "avoid obstructions" are meaningless and must be replaced by a logical array of detailed instructions. The situation can be contrasted to others within the piping design field. For example, consider the problem of the thermal-expansion stress analysis of steam piping that has inflicted so many laborious manhours on the power plant design process in earlier times. Although geometry is important in that problem also, the big thing is numerical evaluation of shape coefficients and the solution of the resulting simultaneous equations—the major task is *computation.* The digital computer can follow essentially the same steps that the human does, hence this device provided welcome relief in one of its first applications to marine engineering. The arrangement problem, on the other hand, requires a negligible amount of computation, but a great amount of practical geometry. It is essentially a graphical problem, and visualization is a human ability not duplicated by the computer.

Should the digital computer be given the job of arranging piping, assuming the handicaps in the area of visualization can be overcome? This I shan't attempt to answer unequivocally, but will point out the incentives for attempting this accomplishment. A first argument is that piping design for a ship is usually a major engineering task—in some cases, several hundred thousand manhours might be expended—but it is largely routine (e.g., does not require the creativity involved in developing hull lines). A second is the practical fact that it already seems feasible to use the computer to check arrangements for the human mistakes that produce interferences among pipes and between pipes and other engineering systems. Many such mistakes inevitably appear in shipboard piping arrangements, and computer methods have been developed by which they are located. Although a great deal of labor must be expended to furnish the computer with the mass of geometrical data, the expense is claimed (by those selling the service) to be justified by the savings that result in building costs. It seems reasonable to at least investigate the next apparent step—instructing the computer to use the geometrical input to construct the arrangements, rather than merely checking it.

What of computer graphics? Readers will perhaps have reacted to my references to the computer's lack of sight by remarking that this deficiency is remedied by graphical displays and inputs via the graphical devices. If the human were not present to interact with the computer in this way, however, it would still be blind. Without the human, the graphics capability is of no value. My intention is to eliminate human participation in the design process, hence graphic interaction is ruled out. Of course, it may indeed turn out that a compromise between total human design and total computer design will prove to be the optimum. But meanwhile one must see just how far the computer can go.

Some work toward the goal of completely computerized piping arrangement has been done in our department. Progress has recently been reported.[1,2] In this article, I shall briefly outline what has been accomplished, discuss a few detailed aspects, and point out the continuing problems.

The Routing Problem. The capability developed to date is this: Given the coordinates of two terminals to be connected by a pipe, the coordinates of one or more terminals to be connected by branches from the main pipe, coordinates of the compartment boundaries, coordinates of the corners of forbidden areas in each of several horizontal layers that divide the compartment, a clearance radius and a bend radius, the computer chooses the coordinates of the shortest path for the pipe centerline, avoiding all forbidden places. The path consists of vertical risers and a horizontal route joining the two risers. Most of the work has been done on the problem of routing in the horizontal plane; a discussion of this effort can suggest some of the individual problems.

Look first at Figure 1, a two-dimensional space containing terminals *A* and *B* to be connected by a pipe. The solution is obvious to the eye: A quick adjustment of a straightedge into position, plus a stroke of the pencil, produces an "arrangement drawing" of the best path. The task is almost as simple for a computer. If it is furnished the coordinates of the terminals, elementary analytic geometry produces the equation of the line.

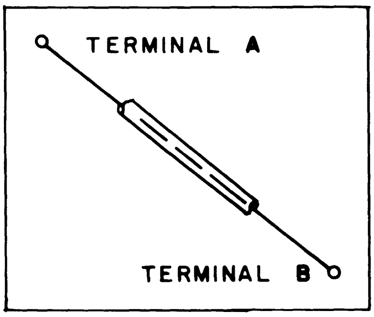


FIGURE 1

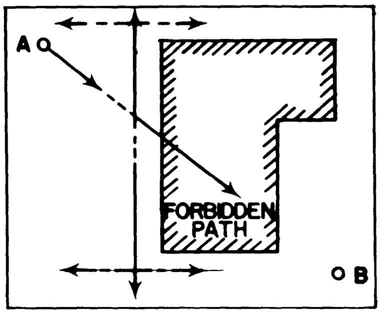


FIGURE 2

Figure 2 poses a slightly—and only slightly—more difficult task for the human. The cross-hatched areas must not be penetrated by the pipe, but the shortest path is readily visualized. The computer faces a more severe test, however. Although it is easy to solve elementary simultaneous equations to locate where the direct path of Figure 1 intersects obstructions, there is no direct way to choose an alternative path. Although several ways appear to be feasible, all require some elements of trial and error groping.

One way, which I call the "sprouts" method, is to generate new lines in directions paralleling the sides of obstructions at every point where a line of a previous generation is intersected. The technique is suggested by Figure 2, wherein a line originating at *A* is shown intersecting an obstruction, giving birth to two new lines offset at a suitable clearance. Each new line in turn gives rise to a third generation, and so on until terminal *B* is reached. Subsequent back-tracing through the family history of any "sprout" reaching *B* delineates a path.

Another method, devised by graduate student Glenn Wangdahl, with guidance from Professor Stephen Pollock (Industrial and Operations Engineering Department)[2], makes use of "control points" located at the corners of each obstruction. See Figure 3. All paths that are candidates for shortest between *A* and *B* are postulated to consist of straight segments joining a select set of control points. The process of choosing these points goes something like this:

(1) All points visible from *A* (an exercise in testing line intersections) form a second generation of points from which a third generation is chosen similarly. (Figure 3 shows the paths to the second generation.)
(2) A fourth generation is formed of those visible from the third, and so on, until point *B* (also treated as a control point) is reached.
(3) Many cases of duplication will appear, e.g., some third-generation points will also be second-generation points. All such duplications are tested to see which path is shortest to *A*. The point is retained only in the generation that belongs in the shortest path. Duplications also occur within a generation (note in Figure 3 that several third-generation points are going to be reached by paths from two second-generation points), and these are also eliminated by retaining the shortest path.
(4) When *B* is reached and duplication checks are completed, the surviving points are the end points of segments delineating the shortest route from *A* to *B*.

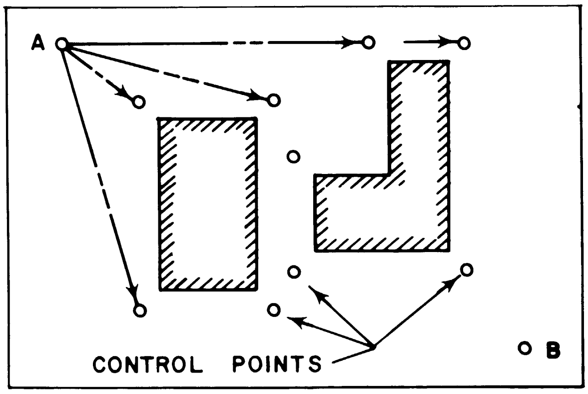
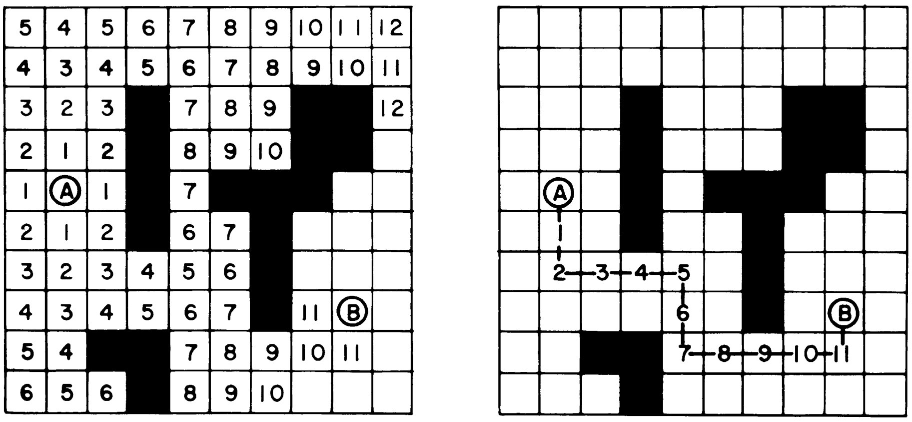


FIGURE 3

A third method is borrowed from the automatic layout of complex electrical circuits; it is known as Lee's algorithm[3]. The method is illustrated by the two sketches of Figure 4. The piping space is laid out into a matrix of cells, some allowable, some forbidden. The method consists of surrounding terminal



APPLYING THE ALGORITHM THE PATH

FIGURE 4

A with a *1* in each cell lying in a coordinate direction, likewise surrounding each *1* with a *2*, etc., until *B* is reached. A path traced back through decreasing numbers is the shortest path. (Where ambiguity is encountered in the back tracing, the rule is to continue in the previous direction.)

Among these three methods, the second appears to be the best on the basis of least computer storage and time. It has obvious defects, however, that keep it from being immediately applicable to practical problems. Since it derives a path that strikes directly across open spaces, it produces paths that often are unacceptable because of inadequate support points. Also, it does not recognize the additional space required for bends and elbows between tangents (but neither do the other two). However, these defects appear to be removable by added programming complexity; they await the attentions of an enthusiastic graduate student.

Many details of elementary analytical geometry are involved in all of this. I'll mention just one, by way of example: In establishing the control points required in the second method, the computer is furnished only with the coordinates of the corners of obstructing objects, and it must compute the control point locations. It must therefore carry out these steps:

(1) Use the corner coordinates to write the equation $\mathrm{Ax} + \mathrm{By} = \mathrm{C}$ of each side of the obstruction.

(2) Write the equation $\mathrm{Ax} + \mathrm{By} = \mathrm{C}'$ of a line paralleling each $\mathrm{Ax} + \mathrm{By} = \mathrm{C}$ at a perpendicular distance R.

(3) Find the intersection of each pair of adjacent lines $\mathrm{Ax} + \mathrm{By} = \mathrm{C}$.

A typical complication is that two lines are found in step (2), one being an unwanted line inside the obstruction. An "insideness" test must consequently be included that will work infallibly for any plane figure bounded by straight line segments. Perhaps a reader well-versed in analytical geometry will know immediately how this can be done. But for the reader whose major talents lie elsewhere, it may be a challenge—I'll leave it as an exercise for such readers.

In Three Dimensions. The control-points method, in particular, seems directly adaptable to three-dimensional space. However, the concept that has been pursued in programming so far is that a piping system is to consist of vertical risers joined by a horizontal path at some appropriate level. The approach is to divide the piping space into horizontal layers spaced a minimum of one bend radius apart. Nominally, a riser from each terminal appears in each layer as a point having the coordinates of its associated terminal. But an obstruction may be in this path, as suggested by Figure 5. The process of constructing the riser therefore consists of a layer-by-layer check to see if this point falls within (the same "inside-or-outside" problem as just mentioned) or too close to a forbidden area. If it does, the computer seeks an alternative path, as suggested in Figure 5. After both risers are completed, then a route is chosen in each layer. The one that produces the shortest total path is retained as the best.

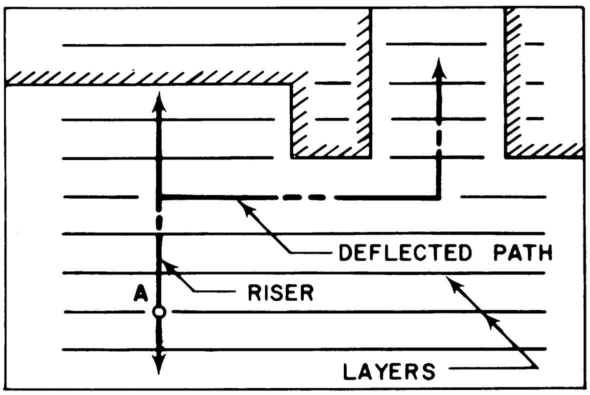
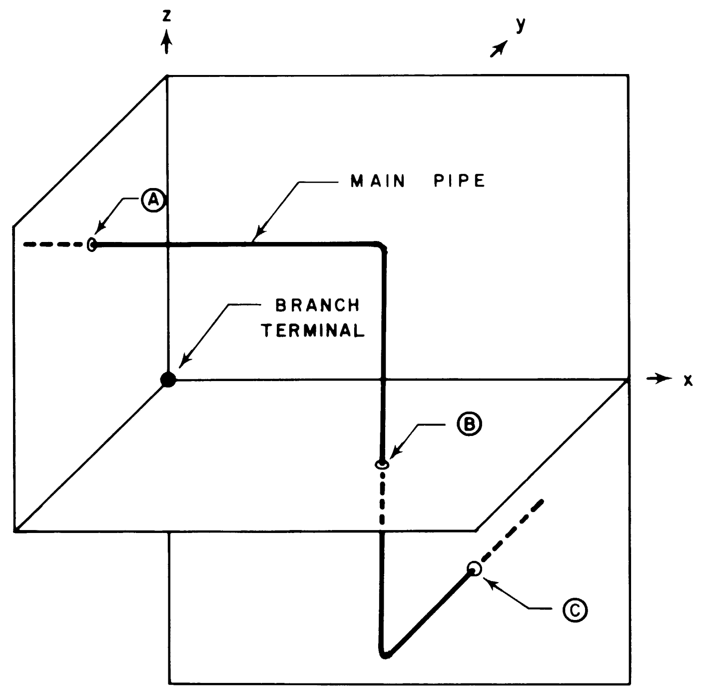


FIGURE 5

Branches. The programming completed so far has the capability of running branches from the main pipe. The process is the same, but it requires the additional feature of locating the branching point on the pipe first constructed. This is done by passing three coordinate planes through the branch terminal and placing a branching point where such plane intersects the main. The one that eventually provides the shortest branch is retained. See Figure 6.



Ⓐ Ⓑ Ⓒ TRIAL POINTS FOR BRANCH TO JOIN MAIN

FIGURE 6

Of course, none of the three planes may intersect the main, in which case they are translated in coordinate directions until at least one does intersect. Also, a branch route can coincide in part with the main. If so, the point of coincidence nearest the branch terminal replaces the previous choice of branching point.

Additional Work. The previous discussions obviously do not describe a system that can now be applied in actual design work. Many additional features to handle the complexities of real piping systems must be added. Some are recognized now, and others will surely be encountered as the programming is tested in increasingly realistic situations. The biggest problem of all appears to be the provision of multi-system capability, with individual arrangements being adjusted to produce overall optimality (perhaps minimum total piping weight).

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References

1. John B. Woodward, "Arrangement of Shipboard Piping by Digital Computer," International Symposium on Marine Engineering, Tokyo, 1973.

2. Glenn Wangdahl, Stephen Pollock, & John B. Woodward, "Minimum Trajectory Pipe Routing," *Journal of Ship Research,* Vol. 18 (March 1974).

3. Sheldon B. Akers, Chapter 6 of *Design Automation of Digital Systems,* Vol. 1, Melvin Breuer, ed., Prentice-Hall, 1972.

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"Optimization in Pre-Contract Ship Design," ICCAS Conference, Tokyo, (August 1973).

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"The Wave Generated by a Fine Ship Bow," *Ninth Symposium on Naval Hydrodynamics*, Paris, France, (August 1972); also: Report No. 127, Department of Naval Architecture and Marine Engineering, The University of Michigan, October 1972.

"The Chertock Formulas for Computing Unsteady Fluid Dynamic Force on a Body," *Zeit. angewandte Math. u. Mech.*, **53** (1973) 573–582.

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"The Fundamental Assumptions in Ship-Motion Theory," *Proceedings of International Symposium on the Dynamics of Marine Vehicles and Structures in Waves*, University College London, (April 1974); also: Report No. 148, Department of Naval Architecture and Marine Engineering, The University of Michigan, February 1974.

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"Long-Range, Energy-State Maneuvers for Minimum-Time to Specified Terminal Conditions," AIAA Eleventh Aerospace Science Meeting, Washington, D.C., (January 1973), (with A. E. Bryson, Jr. and W. C. Hoffman), to appear in the *Journal of Optimization Theory and Applications.*

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"Water Re-Use Aboard Great Lakes Commercial Vessels," AIChE Water Re-Use Meeting, (1973).

"Simulation in Ship Design," *Management Informatics*, Vol. 2, (April. 1973).

"Diesel Power Plant Heat Balance," Technical & Research Bulletin 3–17, The Society of Naval Architects and Marine Engineers, (1973), (with Robert Giblon, Robert Beadle, Jens Holm, A. P. Kiraly, Robert Koch, Hilary Rolih and Joe Snyder).

"Importation of Bulk Raw Materials to Coastal River Sites," Marine Technology Society Annual Meeting, (1973).

"Piping Layout by Digital Computer," International Marine Engineering Conference, Tokyo, (1973).

"Minimum Trajectory Pipe Routing," *Journal of Ship Research,* Vol. 18, (March 1974), (with Stephen Pollock and Glenn Wangdahl).

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see Callis, Majumdar, Nowacki, Stallone and Swift.

TAKAHEI, TETSUO
"A Study on the Waveless Bow," June 1960, 40 pp, 6 ref, included in *Three Recent Papers by Japanese Authors on the Effect of Bulbs on Wave-Making Resistance of Ships,* translated (September 1969) by H. C. Kim. See Inui, Kumano, Takahei; also Kumano. No. 032 $4.50

TASAKI, RYO
see Yokoo and Tasaki.

TEKEZAWA, S.
A Study on the Large Bulbous Bow of a High-Speed Displacement Ship (Part I—Resistance Tests in Still Water, November 1961; Part II—Performance in Waves, May 1962), 36 pp, 13 ref. No. 078 $1.25

TORO, ANDRAS ISTVAN
Shallow Water Performance of a Planing Boat, April 1969, 32 pp, 4 ref, S. No. 019 $2.25

TOWNSEND, WILLIAM H.
see Kaldjian, Townsend, Kahn and Huang.

Troesch, Armin, and Robert F. Beck
Experiments on Ship Motions in Shallow Water, March 1974, 27 pp, 10 ref. No. 149 $1.20

Tsuchida, Kiyoshi, Koichi Yokoo, Atsuo Tazaki, Shigeo Moriyama and Seizo Ohashi
Systematic Resistance and Propulsion Test with Models of Single-Screw, Full-Bodied Oil Tankers, translated from *Japanese Ministry of Transport Ship Research Institute Report*, Vol. 1, No. 6, by J. Moss and Y. Shen (September 1969), 53 pp, 3 ref. No. 039 $2.25

Tuck, Ernest O.
Low-Aspect-Ratio Flat-Ship Theory, June 1973, 40 pp, 20 ref. No. 144 $2.00
see Ogilvie and Tuck.

Vorus, William S.
An Integrated Approach to the Determination of Propeller-Generated Vibratory Forces Acting on a Ship Hull, March 1971, 91 pp, 27 ref. No. 072 $3.00

Wagner, Kenneth E.
see Lutkus, Piché and Wagner

Wagner, Michael
Rational Methods for Engine Rating, May 1970, 17 pp, 1 ref, **S.** No. 090 $ .75

Wangdahl, Glenn
The External Penalty Function Optimization Technique and Its Application to Ship Design, June 1972, 51 pp, **S.** No. 129 **OP U Micro**

Weinblum, Georg
Problems of Naval Architecture, February 1971, translated by D. Meyer-Detring, 21 pp. No. 107 $1.10

White, William N.
Feasibility Study of a Subseatrain, February 1969, 45 pp, 20 ref, **S.** No. 011 **OP U Micro**

Woodward, John B., III
Analysis of Steam Propulsion Plants, May 1971, 68 pp, 3 ref, **T.** No. 108 $3.00
The Diesel Engine: To Drive a Ship, January 1971, 278 pp, 85 ref, **T.** No. 105 $13.20
Fresh Water Supply Aboard Ocean-Going Merchant Ships: The Economic Merit of Distillation from the Sea, 1968, reprinted from *Marine Technology*, April 1969, 13 pp, 19 ref. No. 022 $1.75
Head and Flow Calculations for Piping Design, January 1971, 78 pp, 28 ref, **T.** No. 103 $6.60

Matching Engine and Propeller, June 1973, 35 pp, 7 ref, **T**.
No. 142 $1.75
Sewage Control for Great Lakes Vessels, January 1972, 166 pp.
No. 117 $5.00
Small Craft Engineering—Propulsion by the Internal Combustion Engine, October 1971, 241 pp, 14 ref. No. 122 $10.00
Sophomore's Introduction to Marine Machinery, September 1970, 24 pp, 2 ref, **T**. No. 089 **OP U Micro**
Waste-Heat Distillers in Small Craft: Some Engineering Considerations, January 1972, 28 pp. No. 116 $1.00
see Nowacki and Woodward.

YAZAKI, ATSUO
see Tsuchida, Yokoo, Yazaki, Moriyama and Ohashi.

YOKOO, KOICHI
see Tsuchida, Yokoo, Yazaki, Moriyama and Ohashi.

YOKOO, KOICHI AND RYO TASAKI
On the Twin-Hull Ship (No. 1), 1951, translated (September 1969) by H. C. Kim, from *Report of Transportation Research Institute of Japan*, Vol. 1, No. 1, 20 pp, 9 ref. No. 033 $1.25
On the Twin-Hull Ship (No. 2), 1953, translated (September 1969) by H. C. Kim, from *Report of Transportation Research Institute of Japan*, Vol. 3, No. 3, 9 pp. No. 034 $1.25

YOUNG, BERNARD J.
Computer-Aided Approach to Optimizing the Design of Sailing Yacht Rigs, April 1970, 31 pp, 5 ref, **S**. No. 077 **OP U Micro**
see Nowacki, Moss, Snyder and Young.