Ship Model Basins – The Next 75 Years

Marshall P. Tulin

A Contribution To The 75th Jubilee Meeting Of The VWS – W Berlin

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BY

Marshall P. Tulin

HYDRONAUTICS, Incorporated
Laurel, MD., USA

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Prologue.

In 1773, as wooden sailing ships approached their maturity, Leonhard Euler, court mathematician to Frederick the Great, wrote, Reference 1:

> "From good Models in Miniature which represent Vessels exactly as they are, very important Experiments upon the Resistance of Vessels may be very usefully made; and which is so much the more necessary, as the Theory upon the Subject is still very defective."

Euler referred to tests normally conducted outdoors using a towing cable driven by a falling weight, comparative tests whose results in fact often ran counter to full scale results. It was only in the next century that Ferdinand Reech in Paris (1852) and, independently, William Froude in England (1867) discovered the law of similitude or scaling which comprised the foundation for all ship model testing, thus introducing into modern engineering consciousness the practical importance and proper usage of scaling laws, and establishing the testing of scales models as a science, not only in Naval Architecture but eventually in Aeronautics too.

Froude went on, see Reference 2, and virtually with his own hands created the Towing Tank itself, in a form not very different from what we know today. He worked just at the time when steam propulsion, iron ships, and the screw propeller were gaining widespread acceptance. As a result it had suddenly happened that the ship's resistance had to be known in advance of the ship's construction, for the design of the propulsion machinery depended on it. The timeliness of Froude's great creation was no coincidence, for Froude had himself a close working connection with shipbuilding through that great engineer-innovator, Isambard Brunel, for whom he had successfully carried out analyses of ship rolling, specifically on behalf of the Great Eastern. And Froude's proposal for the first enclosed model basin at Torquay was actually <u>in response</u> to a request from the British Admiralty for means to estimate ship resistance, and his work was financially supported by the Admiralty, albeit inadequately.

<u>Looking Forward</u>.

So much for the origin of our present subject. Now on the happy occasion of the 75th Anniversary of the VWS, a laboratory of important historical significance itself and one which has seen much change during its lifetime, I thought it worthwhile to look forward. And why not look forward much further than we are ordinarily used to? For an obvious reason I chose 75 years. And why not ask colleagues in different corners of the world to share this difficult task? I did this, mainly by posing to them a number of questions (see the Appendices), of which the first was:

Q: Which new tasks will model basins undertake in the long range?

Two replies were:

- Wm. Cummins (NSRDC, Washington): '...whatever the support of the maritime industry requires. We tend to be responsive and our innovations are directed toward the support of our ability to respond.'
- Masao Kinoshita (Hitachi Zosen, Tokyo): 'Technology required for future model basins largely depends upon the progress or change of "the ship" herself. (ice-breaking cargo ship, seaworthy-super-high speed semi-submergible cargo ship, etc.)'

To emphasize the important point they both seem to have made, I would put it thus:

- The future development of ship research and its laboratories depends to a great extent on future developments and resultant needs in Ocean Engineering.

To convince myself of the historical correctness of this view, I attempted to match a number of the most important historical developments in ship model basins with those external events from which the experimental needs seem to have arisen - Table I.

The Table serves an additional purpose for it reminds us that changes in ship model basins have been especially profound during the last few decades, in terms of the variety and sophistication of facilities in use. What the Table only hints at is the large concurrent expansion in the number of ship model basins operating in the world, and in the remarkable improvement in instrumentation and techniques which has taken place during the same period. Here, the effect of contemporary technological revolutions - in electronics and in digital computing have had really revolutionary effects on dynamometry, wave and motions measurement, data acquisition, storage and processing.

Regarding new future tasks for the ship model basin, we have in light of Table I only (!!) to predict what it is that history will demand of ocean engineering and, in turn, what ocean engineering will demand from the laboratories. Here I would emphasize that as great as the expansion in ocean engineering and in model basin tasks has been during the last twenty years or so, ocean engineering seems to be in a phase of rapid growth and proliferation of challenge. There seems little doubt that the seaward thrust of peoples and nations is as great as it ever was, and that the force of this thrust is now augmented by the power of modern engineering and new technologies.

What will these challenges be during the next seventy-five years? It is of course far easier to ask some simple questions, looking ahead to the year 2053; and I invite you to ask others:

- What type and volume of world trade will exist, and will the bulk of it still largely be carried on the sea? (Alternatives, for example, are: large gravity-drive thru-earth tunnels, pipelines, and solar powered aircraft.)
- What will be the size and speed of trade carrying ships? Is there a practical engineering limit to the size of ships? Will a practical means be discovered for substantially reducing frictional and wave-resistance?
- Will ships still largely be propelled with fossil fuel engines and screw propellers? (Alternatives, for example, are completely internal, magneto-hydrodynamic propulsors with cryogenic magnets and a fusion power source.)
- What radically new ship types will be discovered and developed? (The aircushion vehicle is an example from the last few decades.)
- When will offshore oil and mineral developments have reached a peak in terms of magnitude and engineering innovation? What are the major innovations lying between the present time and the peak?
- Does Ocean Engineering face other challenges similar to the offshore oil expansion of the last few decades, and what are they?

- Will the ocean bottom be in future the scene of extensive activity, even colonization?

Short of answering such difficult questions as these, what can we predict concerning the future of model basin tasks? Here are a few answers given by my colleagues:

- J. Gerritsma (Technische Hogeschool Delft): 'New tasks for model basins will be more and more associated with the exploration of the sea and the sea bottom. Offshore work as carried out now seems a start in this direction. There is an increased collaboration between ship hydrodynamics and hydraulic engineers and a further use of experimental model techniques to study the behavior of floating and underwater objects other than ships.' 'I do not believe that experimental facilities should grow too fast. Ship model basins should focus on more fundamental experiments to check theories, rather than carry out too much empirical tests.'
- E. Baba (Mitsubishi Heavy Industries, Nagasaki): 'Research staffs of Nagasaki Tank are doing both design and basic research. Their today's new findings in hydrodynamic research are applied to the ship form design at hand. This system will surely be continued in the Nagasaki Tank. This system helps to stimulate research staffs. New research topics came from their practical design experiences.'

- Klaus Kruppa (Technische Universität Berlin): 'Model Basins will get more and more involved in design and take on design responsibility.' '...the procurement of full scale data will also be one of the major responsibilities of the Model Basin.' 'Model Basins will require structural analysis capability' '...foresee a strong interest in hydro-acoustics of non-military nature in Model Basins.'
- D. van Manen (NSMB, Wageningen): 'In the last years, two important factors started influencing this symbiosis of phenomenology, theory and experiment. These two factors are:
  - Measuring techniques reached a quality permitting full scale measurements to be performed successfully, though still under incidental circumstances, which were difficult to reproduce at relatively high costs.
  - Very powerful computer programs became available for the study of fundamental problems, into which up to now we do not dare to penetrate. In this respect could be mentioned: The boundary layer of a ship, various viscous effects and fundamental components of the phenomenon "cavitation" and forces on maritime constructions in waves.'

Four important predictions would seem to emerge from these replies:

- The technical and scientific scope of model basin activity will continue to broaden, into fields such as hydro-acoustics, structural analysis, and soil mechanics. This list can easily be extended: materials and coatings; geophysical fluid dynamics, marine pollution control, marine economics and systems, etc.

- Model basins will get more and more involved in design, as is already the case with those tanks associated with industry, as Mitsubishi, and which operate on a commercial basis, as HYDRONAUTICS.
- Full scale trials and data acquisition will become a major responsibility of the model basin.
- The combination of digital computer and theory offer opportunities to provide useful information, heretofore not available.

The Computer as Partner.

I had, in fact, made a special issue of the role of digital computers by asking my colleagues several questions concerning the future of computers in ship model basins. One of these concerned the possibility of a mutually beneficial partnership. It was:

> Q: For which tasks will the basin and computer be used together to supply better answers?

Some of their replies:

- G. Gadd (National Maritime Institute, Feltham): 'In the foreseeable future I would expect towing tank and computer will be used together for improved hull design with regard to calm water resistance and propulsion. The computer will be used to select the most promising out of a range of possible designs for low wave resistance and for wake contours likely to minimize propeller-excited vibration. Only after such a preliminary optimization process will a model be made and tank tested.'
- J.N. Newman (MIT, Cambridge): 'Tasks where turbulence is a factor, including ship resistance and maneuvering, and the separated flow past bluff bodies, seem unlikely to be divorced from experimental facilities. Nor is it likely that the scale effects associated with these same problems can be adequately dealt with, and except for routine experimentation these seem to be tasks where the basin and computer will have to be used together to supply better answers. Perhaps the current developments of semi-empirical three-dimensional boundary-layer computations will facilitate such an interchange.'
- R.B. Couch (Univ. Michigan, Ann Arbor): 'In the case of normal ship problems where viscous forces are important.'
- E. Baba: 'The model basin and computer will be used together to supply better answers in the following tasks.

'Prediction of propulsive performance, seakeeping and maneuvering quality of ships. A large number of accumulated model test data and sea trial data of long years are stored in the data file of the computer. Designer of ships can readily pick up his desired data from the file by means of graphic display. In order to attain the desired performance, the improvement of ship form and propeller is carried out by the help of available theoretical calculations; wave resistance calculation, viscous boundary layer calculation, viscous pressure resistance calculation, calculation of viscous wake, calculation of interaction effects between ship, propeller and rudder, calculation of propeller surface forces and bearing forces, ship motion calculations and so on. Model tests are also planned and carried out for the confirmation.'

- W.E. Cummins: 'During the current interim period (basin and computer are already intimately coupled) the use of computer will continue to grow. Current or near future examples - experiment and theory to estimate full scale structured wake for propeller design. As our mathematical models improve, the physical model will decline.'
- H. Maruo (Yokahoma Nat'l Univ.): 'Propulsive performance prediction of full scale ships. Prediction of steering motions.'

- K. Kruppa: '...motion simulators and associated control loops will require model data input for computer simulation, especially when non-linear characteristics complicate the mathematical model.'
- J. Gerritsma: 'Experience in Delft has shown, that ship motions in a seaway, steering and maneuvering are examples of work that can be taken over partly by computers. In particular in seakeeping work numerical methods were soon available to evaluate the dynamic responses experiments. To this end none or less fundamental experiments were necessary to check the theoretical methods in an early stage. This combination of experimental and analytical methods seems very useful, at least for studying dynamic phenomena, and it is expected that more problems will be attacked in this way in the future. An example is the forced oscillation technique which provides the necessary information for ship maneuvering simulation in a realistic time scale. Simulation technique is not restricted to conventional ships, but also other large floating stuc-tures, as used in offshore work, can be studied in this way.'

A very strong prediction emerges in these replies:

- That the computer will become a powerful and necessary accessory of the ship model basin for the analysis and prediction of both the propulsive performance of ships and of maneuvering.

The Computer as Competitor.

Will the partnership between computer and model basin evolve into a real competition? I had asked my colleagues this question:

Q: Which old tasks will be taken over by computer?

Some answers are:

- W. Cummins: 'Most of them. Our role has now almost completely shifted from guiding design to confirming design because the model comes too late to influence design very much. In addition, improved potential and viscous flow theory will permit direct calculation of drag, powering, maneuvering and seakeeping. Confirmation of design will remain essential, and providing the empirical base for advancing theory will be important for many years.'
- H. Maruo: 'Ship motion prediction both in regular and irregular seas. Propeller open water characteristics. Planning of hull lines. Systematic storage of optimum hull forms, with hull parameters and analytical representation of hull lines, in computer library, which can be recommended to ship builders and ship designers to utilize without individual tank tests (a new technique).'

- R.B. Couch: 'Hydrodynamic problems which are largely Froude Law governed may well be almost all solved with the use of a computer.'
- J.N. Newman: '...the computer will take over those tasks where viscosity and separation are not important. Examples are moderately loaded propellers, and ship motions in waves of moderate severity (excluding roll).'
- K. Eggers (Universität Hamburg): 'Wieghard's prognosis is, that viscous resistance still will have to be determined by experiment, but wave resistance "as this is nicely defined mathematically" should be treatable by numerical approach. I cannot share this optimism from my experience.'
- G. Gadd: 'Before the end of the 75 year period it may be possible to cut out the experiments altogether if propulsive efficiency can by then be estimated reliably. It will be unnecessary to perform special experiments to determine flow directions over the hull for the alignment of appendages, or pressures at points on the hull: the computer will do such tasks more easily. Experiments on ship motions in waves may also become unnecessary, except for the largest waves.'

- K. Kruppa: 'All methodical series data, concerning resistance, propulsion and propeller tests, will be available on the computer. Standard single screw merchant ship model tests will be a thing of the past and will be replaced by more reliable analytical predictions. At the same time hydrodynamic coefficients of standardized ship forms will become readily available and can be used for motion prediction, both with regard to motions in a seaway and maneuvering.'

- P. Pien (NSRDC, Washington): 'Hydrodynamic theory has not yet been used routinely in solving ship hydrodynamic problems. However in recent years, the field of Numerical Hydrodynamics has made a very impressive progress. In the near future, it will be possible to compute the pressure distributions on a ship hull advancing with a constant velocity in calm water and to replace the present EHP test by a computer.

  As time goes by and the computer becomes faster and faster with larger and larger capacity, the pressure distribution on a ship hull sailing across the sea can be accurately computed. At that time, the present method of obtaining hull dynamic coefficients by model testing can again be replaced by a computer.

At the present time, propeller theory is satisfactorily used in propeller design. It can also be used to predict the open water performance of a given propeller with various degrees of success. When the propeller theory is further improved, no more propeller open water tests would be necessary. Then the present SHP test can also be omitted.

In view of the rapid advancement of technology in the field of ship hydrodynamics, a period of 75 years is a long time. I am quite optimistic that at some point of this time period, most of the present day experiments conducted in calm water will be replaced by computers.'

With one exception, my colleagues strongly lean to the prediction:

- In the 75 year period, the computer will eventually have replaced the towing tank for <u>many</u> of the tasks required today for ship design or design confirmation, particularly ship motions predictions.

Several replies suggest that:

- Planning of hull lines and propeller design will be carried out by computer, using both computer libraries of available data and analytical predictions of resistance and propulsion.

Unquestionably, though, many (not all) replies show a general skepticism concerning the long-range ability of computer aided theory or numerical hydrodynamics to deal with problems involving viscous flow. This surprised me, since the application of computational fluid dynamics to aircraft and space applications has already reached an impressive and practical stage, well beyond that yet realized in the field of ship hydrodynamics; and further rapid progress is predicted. At a meeting in Washington, D.C. in 1975, devoted to a discussion of the potential of numerical hydrodynamics as a design tool for naval architects and hydrodynamicists, the following conclusion was reached by Robert W. MacCormack of the NASA Ames Research Center at Moffett Field, California [Reference 2, page 226]:

- 'During the last decade we have witnessed a considerable amount of progress in computational fluid dynamics. This progress has enabled us to extend our two-dimensional inviscid supersonic and transonic flow calculations to three-dimensional flows past wing-body combinations using about the same computer time as before. In a sense our status for viscous flows is where we were for inviscid flows a decade ago. It is not unexpected that a decade from now it will be practical to numerically simulate high Reynolds number viscous flows about complete aircraft configurations.'

In the long range, too, must we not assume the impact of a continual dynamic evolution in computer hardware itself, to say nothing of the possibility for new revolutions in computer related technology? For example, the laser, which is just finding large scale practical application in the communications industry, has yet to find the same application in production computers. This optimistic view of computer developments seems reflected in the remarks of one of the respondents:

- W. Cummins: 'Hardware and Software Changes are already well underway. Directed at the efficient collection and analysis of large masses of data at one end, the development of fast large memory computers at the other. Real progress in numerical hydromechanics is now being made. The handling of enormous data bases is one of the most critical problems.'

Now, in the face of the strong competition which computers will increasingly offer towing tanks, I would like to ask all of you this question:

Q: Even if it should eventually be possible to replace the model basin by the digital computer, is it to be recommended?

I personally find a great deal of sympathy with the view of my colleague, E. Baba:

'Human resources such as skilled draftsmen of lines fairing (creating), skilled workers for manufacturing of ship models and experts of experiment should be kept and continuously be supplied through on the job training. New hydrodynamical findings are often brought by such experts. The computer should be used partially to help them. Complete take-over by computer is not recommended.'

I would make a related suggestion. If the replacement of most old tasks by digital computers is, in fact, inevitable, perhaps model basins should insist to replace such tasks with new or extended tasks of a searching and inventive nature. I think that all industries utilizing the model basin will profit from added emphasis on such activities, whether they be called research or something else. And in this way we can preserve and even foster the application of human insight and creativity to ship problems, which, as Baba seems to be saying, the complete take-over by computer threatens to restrict.

New Equipment.

Most of us would like to believe that the model basin has in fact by 2053 not been replaced by a small console connected to a large computer situated at some remote site. Then, what will the model basin actually look like and what kind of instrumentation and techniques will be in use? I had asked my colleagues:

Q: What changes in equipment and techniques can be contemplated?

Among the replies to this difficult and relatively unpopular question:

- T. Inui (Tokyo University): 'Measuring techniques are needed for coordinating 3D boundary layer theory and the actual flow phenomena, particularly with respect to flow separation problems.' '...measure the wave contours (= map of wave)..., particularly that of the bow wave.'
- K. Eggers: '...there will be circulating water tunnels with the model fixed.'
- M. Kinoshita: 'A new task and a new technique to find out a ship form with minimum wave resistance at service speed, using an elastic ship model which has many water pressure sensors over its underwater surface will be undertaken. The form of this model can be changed until a form with minimum wave resistance is obtained, according to the water pressure measured over its underwater surface by the aid of a computer control system, under a certain condition such as "keeping L, B, d and Δ constant" and so on.'

  'New techniques...will be introduced to make a flow visible. In this case a flow means not only a flow over the surface of a model but also a flow around a model, especially near the bottom of bow part, bilge vortices and in the diverging flow at the stern part.'
- H. Maruo: 'Full automation of tank test facilities including routine measurement of wave pattern and wake distribution around models.'

- J. Gerritsma: 'At this moment experimental instrumentation is very advanced. It seems difficult to wish more than is available now. Instrumentation should be versatile and suited to attack more fundamental experiments of various nature rather than designed for specified standard tests.'
- R.B. Couch: 'Equipment particularly for dynamic measures must be improved so that multiple measurements using electronics equipment are more reliable - space technology perhaps.

The first two respondents remind us of the need for rapid, extensive utilization and/or quantitative measurement of flow patterns in model basins, a need which also exists in other laboratories, and in full scale engineering situations of all sorts. I personally think it highly probable that such measurements and visualization (perhaps via sensor driven computer reconstructions) will become commonplace long before 2053; both the laser and small phase-array acoustic devices already offer impressive tools, and others no doubt remain to be invented.

One can easily predict, too, for the near future anyway, the widespread and general use among towing-tanks of new techniques introduced during the last few decades or alternatives even to be invented, including: wave and wake surveys, planar motion oscillation measurements, testing of entire hull-propeller combinations with cavitation simulation, wave-wind-current simulations, motion simulators, ice-testing, etc. And these will undoubtedly be joined by other facilities, equipment, and techniques required for the solution of large problems still to arise. How can this be doubted in view of the rapid changes which have occurred in only the last few decades?

Concluding Remarks.

Going beyond the physical plant and back to some of the earlier predictions here, pgs. 7 - 8, I would emphasize that at least some of our largest and most active model basins will find their activities increasingly more widely diversified in one or all of the following ways:

- genuine multi-disciplinary research and system studies.
- specialized design.
- full scale trials and measurement.

and even,

- hardware system development.

In addition it would seem that the number of model basins in the world will be greatly expanded by 2053, to virtually all of those nations with significant population and trade, including most of those which are now officially classified as underdeveloped or developing (most are in the Southern hemisphere). This implies an even more highly competitive atmosphere among independent model basins, and this fact lends additional spice to the pursuit of growing apportunities which lie stretched out before us in our task to serve the ocean engineering community.

In closing I wish especially to thank all of my colleagues see the Appendix, who have been kind enough to give me their views on this subject and permit me freely to quote them; without their fine response, this paper would not have been possible. It reminds one again that the Model Basin Community is closely knit and enjoys a degree of cooperation and comraderie unknown in many other fields of activity; I like to imagine that this spirit is part of an old inheritance associated with man's intimate relation and struggle with the sea. It is, anyway, highly valued by many of us, as well as it should be, and above all we look forward to passing on that spirit during the next 75 years.

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TABLE 1 A CORRELATION BETWEEN MODEL BASIN DEVELOPMENTS AND EXTERNAL EVENTS

YEAR	MODEL BASIN DEVELOPMENT	EXTERNAL EVENTS
16– - 18–	Gravity Tow, Comparative Tests, in Ponds. Euler (1773).	Worldwide Trade and Colonization. Warfare between European Nations.
1870 -	Enclosed Tank, Dynamometry, Propeller Towing. Wm. Froude	Steam Propulsion, Iron Ships, Screw Propeller.
1890 - 1910	Water Tunnel w. Simulated Cavitation. C. Parsons.	Steam Turbines. High Ungeared Rotative Speeds.
1900 - 1915	Many New Towing Tanks.	Naval Armaments Race.
1930	Modern Cavitation Tunnel (vacuum). Kempf and Lerbs.	Increased Speed and Power of Liners and Warships.
1936	Rotating Arm. Paris.	Maneuvering of Warships and Submersibles.
1953	Submarine PMM. Gertler and Goodman.	Evolution of True Submarines from Submersibles.
1955	Large Scale Computing Facility. NSRDC - Washington	
196– → Present	Many New Towing Tanks.	Growth in World Tonnage and New Shipbuilding Nations.
1962	Free Surface Cavitation Tunnels. Hydronautics.	Hydrofoil and ACV Developments.
1965	Wave and Current Simulators - Harbors. Wageningen	Harbor Development and Increased Offshore Operations.
196–	Surface Ship PMM. Berkeley; Lyngby	Below, and Ship Autopilot Acceptance.
196–	Ship Handling Simulators. Wageningen.	Supertanker Developments - Low Speed Maneuvering.
197–	Vacutank. Wageningen. Cavitation Tunnel for Entire Hulls. SSPA Large Free Surface Cavitation Tunnel. VWS	Rapid Increase in Power Absorption and Vibration Due to Cavitation. High Speed Cavitation Problems.
197–	Wake Survey Applications. Baba	Supertanker Development.
197–	Wave Survey Applications. Inui et al.	Increasing Speed and Power of Cargo Ships.

APPENDICES

HYDRONAUTICS, INCORPORATED
RESEARCH IN HYDRODYNAMICS
7210 PINDELL SCHOOL ROAD, HOWARD COUNTY, LAUREL, MARYLAND 20810 — TELEPHONE 776-7454

July 24, 1978

Dear

As you may know, in November of this year the Berlin Towing Tank (Versuchsanstalt für Wasserbau und Schiffbau) will be celebrating its 75th Jubilee, and on that occasion will host a symposium "on future tasks and problems of model basins in predicting the behavior of ships and of hydraulic, coastal and ocean engineering structures."

I am preparing a short paper for this symposium, which will be presented at its start, in which I would very much like your collaboration. The subject is:

"Ship Model Basins - The Next 75 Years"

In this paper I will consider a number of questions concerning the future of ship model basins, including the following:

- o Which new tasks will model basins undertake in the long range?
- o Which old tasks will be taken over by computer?
- o For which tasks will the basin and computer be used together to supply better answers?
- o What changes in equipment and techniques can be contemplated?

For this task I intend to integrate the views of diverse individuals (see the enclosed list) close to model basins and/or theoretical developments in ship hydrodynamics. Therefore, I would appreciate your consideration of the four questions above, and answers to any or all of them which readily occur to you. I hope to have your views as an individual, rather than in an official sense. A brief letter in reply, as short as one or two pages, will be welcome. If you do not wish to be quoted directly, please say so.

I hope that I may hear from you soon, and, in any event, before 1 September. I look forward eagerly to read your opinions.

Sincerely,

HYDRONAUTICS, Incorporated

Marshall P. Tulin

MARSHALL P. TULIN

MPT:bmm

Enclosure

ADDRESSEES:

Dr. E. Baba
Nagasaki Experimental Tank
3-48 Bunkyo-Machi
Nagasaki 852, Japan

Prof. R. B. Couch
Department of Naval Architecture
University of Michigan
Ann Arbor, Michigan 48104

Dr. W. E. Cummins
Naval Ship Research and
Development Center
Navy Department
Bethesda, Maryland 20034 USA

Prof. Dr. K. Eggers
Institut für Schiffbau
Universitat Hamburg
2 Hamburg 33, Lammersieth 90
Federal Republic of Germany

Dr. George Gadd
Ship Division
National Physical Laboratory
Faggs Road, Feltham
Middlesex, United Kingdom

Prof. Ir. J. Gerritsma
Delft Shipbuilding Laboratory
Technological University
Mekelweg 2
Delft, The Netherlands

Prof. Dr. T. Inui
Faculty of Engineering
University of Tokyo
7-3-1 Hongo, Bonkyo-Ku
Tokyo 113, Japan

Dr. M. Kinoshita
Hitachi Shipbuilding & Engineering
Co., Ltd.
47 I-Chome Edobori
Nishi-Ku, Osaka 550, Japan

Prof. Dr. Ing. C. Kruppa
Institut für Schiffstechnik
Tech. Universitat Berlin
1 Berlin, 10 Salzufer 17-19
Federal Republic of Germany

Prof. Dr. H. Maruo
National University of Yokahama
2-31-1 Ooka
Minami-Ku
Yokahama 233, Japan

Prof. J. N. Newman
Department of Ocean Engineering
MIT
Cambridge, Massachusetts 02139 USA

Dr. P. C. Pien
NSRDC
Navy Department
Bethesda, Maryland 20034 USA

Prof. Dr. Ir. J. D. Van Manen
Netherlands Ship Model Basin
Haagsteeg 2
P. O. Box 28
Wageningen, The Netherlands