ADVANCES IN MARITIME HYDRODYNAMIC RESEARCH DURING THE LAST CENTURY

BY

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SUMMARY

Progress in maritime hydrodynamic research during the past century, beginning with the experiments of William Froude around 1870, has been discussed in this paper. Such research has been substantially extended over the years to include the effect of shallow water, the behaviour of a ship in a seaway and the manœuvring characteristics of ships. Moreover, not only ships but also floating and fixed structures for the offshore industry have become subjects of hydrodynamic investigation. Many "special purpose" laboratories have been built to carry out this research. Recently numerical methods and computer programs are starting to play a role in the design and operation of ships and offshore structures.

Introduction

The behaviour of a ship at sea, its speed, motion in a seaway, stability and manœuvring characteristics, depends to a great extent on the dimensions and shape of the hull. These dimensions and shape determine the reaction of the ship to the external forces, which in turn are determined not only by the gravity and buoyancy force of the water but also by the thrust force generated by oars, wind or mechanical devices. Moreover, the ship experiences forces on the hull owing to its forward speed, the waves and manœuvring motions. Therefore, determining the hydrodynamic characteristics of a ship is an extremely complicated matter.

In ancient times the hull shape and main dimensions of sailing vessels were developed on the basis of experience. Improvement of the hull form by sophisticated experiments was to risky from a strategic point of view. The success of naval combat actions and voyages of discovery depended very much on the reliability of the ships used.

From the beginning the shape and dimensions of ships have been the subject of scientific considerations, an interest that focussed mainly on the hydrostatics and stability of ships. In Fig. 1 the indication of the waterline on an ancient vessel is shown. The forces acting on the hull in still water without forward speed were considered.

It was probably in the 17th century that scientific interest was shown for the first time in the effect of the forward speed of a ship on the optimum dimensions and shape of its hull. The background for this interest was a result of the investigations carried out by Isaac Newton. He was the originator of the determination of the forces acting on bodies moving in fluid, or hydrodynamics. Since that time many scientists have studied the problem of determining the optimum hull shape of a ship moving in water. In the 17th and 18th centuries research focussed on the hull form with minimum resistance together with favourable stability and sailing characteristics. To derive these characteristics many simplifications had to be introduced, which made the results doubtful for practical application.

Many scientists started using experiments to verify their theories and prediction methods. In Fig. 2 a painting by Anna Zinkeisen is shown of model tests in St. Catherina's Dock in London. In most cases the problems encountered in common practice were not solved. The shipbuilder or naval architect remained responsible for the performance of the ship delivered. The research carried out in the 18th century was still of limited value and no great changes occurred in the shape and dimensions of the hull forms of sailing ships.

The introduction of steam-driven, mechanically powered ships at the beginning of the 19th century led to drastic changes. The hull shapes of sailing ships developed through the centuries needed to be adapted, owing to the great change in the forces acting on the hull. For mechanically powered ships the design of a hull form with minimum resistance was of the utmost importance from the fuel saving point of view. Given the complex nature of the problem, a scientific approach was needed to determine the optimum hull form. In addition, replacing wood by iron and steel as building materials for ships made it possible to design and construct hull forms that differed greatly from the traditional shape and dimensions of sailing ships.

In the following paper certain facets of the development of shipbuilding research, since the introduction of mechanical power for propulsion as well as of iron and steel as construction materials, will be discussed.

From wind to mechanically powered ships

Until 1800 the sailing ship was, as stated in the introduction, the only means of transport for long distances at sea. The transport capacity of such ships was, within certain limits, completely dependent on wind and weather conditions. Their design was determined by tradition and experience, scientific research into the optimum hull form seldom being carried out.

Once mechanically powered ships had been introduced around 1800 naval architects were confronted with many problems. One of the demands, among other design requirements, was the need to ensure that the hull shape and the propulsion arrangement would be as efficient as possible in a hydrodynamic sense. The ultimate goal was, and still is, that the ship would attain the required speed with the minimum shaft horse power, the problem being to obtain the best combination of low resistance and high propulsive efficiency.

The first mechanically driven ships were driven mainly by paddle wheels. The idea of a propulsion device resembling what is now called the screw propeller was certainly not new. The most probable explanation why this was not applied from the beginning in mechanically driven ships is that it was tried and found lacking. This could have been due to the absence of a proper screw configuration and of an engine design that could take full advantage of the propulsive qualities of the screw.

Nevertheless, screw propeller development got under way around 1800. By 1850 or thereabouts it was rapidly replacing the paddle wheel on ocean voyages, and by 1860 it was virtually the only type of propulsion device to be installed in seagoing ships.

The paddle wheel is no longer required for propulsion on inland waters either, because the rivers of the world regularly undergo improvement programmes to increase their width and depth and to control the rate of current. The paddle wheel filled a distinct gap in technical knowledge, however, during the transition from sail to mechanical propulsion. While higher speed marine engines were being developed to drive the more efficient screw propeller, the paddle wheel provided the necessary experience with mechanical equipment at sea.

Increased interest is being shown in the use of paddle wheels for inland cruise vessels nowadays. A recently built stern-wheeled cruise vessel, "Mississippi Queen", is now in operation on the Dutch waterways (see fig. 3). It is satisfying to know that the paddle wheel, which has played such an important role in maritime history, has not been completely forgotten.

Ship model testing

The flow around a ship and the ship's resistance are of a complicated nature. Accordingly, alreay in earlier days recourse was had to experimental methods in studying such matters. Tests have been reported in which small wooden models were towed by a system of ropes and falling weights, a method of testing called gravity towing.

William Froude carried out his first experiments in 1863 using gravity towing too. Dissatisfied with the limitations imposed by such experiments, he turned his mind to the use of a larger tank. His proposals to the British Admiralty were accepted and a new towing tank was completed in Torquay in 1871. This tank was 90 m in length and 12 m in width at the water surface, the water in the centreline of the tank being 3.5 m in depth. It was equipped with a mechanically propelled towing carriage to tow the models.

Owing to its size and the way the models were towed, this tank may be considered the forerunner of the towing tanks in use today. Froude's ship-model basin was really the first scientific industrial service centre in the field of marine technology.

A review of the towing tanks built in the period from 1873 to 1940 is given in Table 1. This review is certainly not complete, because a number of tanks have been taken out of service in the meantime and the smaller university tanks are not included on the list. Since 1940 an ever-increasing number of towing tanks have been built or are under construction. This holds for the past twenty years in particular for the Far East (Japan and Korea). At the moment about 200 towing tanks are in operation all over the world.

At MARIN the work started in 1932 with carrying out resistance and propulsion tests on models in a towing tank. In Fig. 4 an overview of the Deep Water Towing Tank of MARIN is given. This towing tank is a large concrete basin 250 m long, 10.5 m wide and with a water depth of 5.5 m. The dimensions are chosen so that the sides and bottom of the tank have no influence on the resistance and propulsion characteristics of the model. Along the two long sides of the basin a rail is mounted on which a towing carriage, a kind of bridge construction, runs.

During a resistance test the model is connected to the towing carriage, and the force needed to tow the model at a certain speed through the tank is measured. In connection with the resistance tests, propulsion tests can also be carried out, in which the model propels itself by screw propellers driven by electromotors. During the propulsion test the ship speed and propeller thrust, torque and rpm are measured.

Table 1. – Towing Tanks built between 1871 and 1940.

Torquay	UK	1871
Amsterdam	Netherlands	1876
Dumbarton	UK	1883
Haslar	UK	1886
La Spezia	Italy	1889
Ubigau	FRG	1892
St. Petersburg	USSR	1893
Washington	USA	1898
Bremerhaven	FRG	1900
Hamburg	FRG	1908
Nagasaki	Japan	1908
Tokyo	Japan	1910
Teddington	UK	1911
Vienna	Austria	1919
Langley Field	USA	1929
Rome	Italy	1929
Ottawa	Canada	1930
Wageningen	Netherlands	1932
Madrid	Spain	1932
Newport News	USA	1933
Moscow	USSR	1933
Hoboken	USA	1935
Carderock	USA	1938
Delft	Netherlands	1938
Gothenborg	Sweden	1940

International co-operation between various towing-tanks teams was established in 1933. The initiative of organizing a meeting of their representatives was taken by Prof. L. Troost, the President of the Netherlands Ship Model Basin (NSMB) at Wageningen, which at that time had just been put into operation. The NSMB was later named MARIN. In taking this action, Prof. L. Troost was following the suggestion of Dr. Ing. John de Meo, from London, who for a long time had been strongly pleading for international co-operation in the field of ship propulsion.

The first meeting of these towing-tanks representatives led to the International Towing Tank Conference (ITTC) being set up. The intention of the ITTC as described in the preface of the proceedings of the first conference is : "To give tank officials an opportunity of conferring in an open and confidential manner on their methods and also on the manner of publication of tank results."

At the first conference, 23 delegates were present, representing 10 European model basins in 9 countries. The number of towing tanks has grown since then and the 18th ITTC, held in 1987 in Kobe, Japan, was attended by some 300 delegates, representing 80 model basins in 40 countries throughout the world (see also Table 2). Only the major model basins rendering service to the industry are represented at the conference. In addition to the major industry-oriented model basins there are many smaller university towing tanks, used mainly for educational purposes.

Through the years the ITTC has maintained its character of providing a forum for exchanging knowledge and experience between the ship hydrodynamic laboratories. The ITTC has strengthened the significance of predictions for the behaviour of maritime constructions in reality.

Table 2. – Place and year of successive Towing Tank Conferences.

No.	Year	Place	Members
1	1933	The Hague	10
2	1934	London	
3	1936	Paris	
4	1938	Berlin	
5	1948	London	
6	1951	Washington	
7	1954	Gothenborg, Copenhagen	
8	1957	Madrid	
9	1960	Paris	
10	1963	London	35
11	1966	Tokyo	
12	1969	Rome	
13	1972	Berlin, Hamburg	
14	1975	Ottawa	61
15	1978	The Hague	71
16	1981	Leningrad	75
17	1984	Gothenborg	80
18	1987	Kobe	83
19	1900	Madrid	87

Resistance and propulsion

The resistance of a ship is the product of a number of components that interact in an extremely complex way. The four main components are :

- frictional resistance, due to the motion of the hull through a viscious fluid ;
- wavemaking resistance, due to the energy that must be continuously supplied by the ship to the wave system created on the surface of the water ;
- eddy resistance, due to the energy carried away by eddies shed from the hull and appendages. Also, if the end of the ship is too blunt, the water may be unable to follow the curvature and will break away from the hull, again giving rise to eddies and separation resistance ;
- air resistance experienced by the part of the hull above water and the superstructure.

The relative weight of the different components depends on the particular conditions of a design, and the skill of the naval architect lies in his ability to choose the shape and proportions of the hull that will result in a combination leading to the minimum total power. For slow-speed ships frictional resistance will dominate and is responsible for more than 75% of the ship's resistance. In case of a high-speed ship such as a navy frigate the wavemaking resistance may account for over 50% of the ship's resistance.

In ship model testing the following model rules have to be taken into account.

a. Geometric similarity : the form of the model must be geometrically similar to the full-scale ship to obtain the same flow patterns. The size of the towing tank must be such that there is no influence on the flow pattern around the ship attributable to the bottom or sides of the tank.

b. Kinematic similarity : the ratio between the velocity components must be similar at model and full scale. For the ship's propeller this means :

$$J = \left(\frac{V}{nD}\right)_{\text{model}} = \left(\frac{V}{nD}\right)_{\text{full scale}}$$

where J = advance coefficient ; V = ship speed ; D = propeller diameter ; n = propeller rate of revolutions.

c. Dynamic similarity : the forces at model and full scale must be similar in ratio. This holds for the absolute values as well as for the directions. The particular model rules are :

Model rule of Froude :

$$F_r = (V/\sqrt{gL})_{\text{model}} = (V/\sqrt{gL})_{\text{full scale}}$$

Model rule of Reynolds :

$$R_e = (VL/\nu)_{\text{model}} = (VL/\nu)_{\text{full scale}}$$

in which V = ship speed ; L = ship length ; g = acceleration due to gravity ; and ν = kinematic viscosity.

For ship models it is impossible to satisfy the model rules of Froude and Reynolds at the same time. The accepted basis for predicting ship resistance from that of the model still rests on the assumption made by Froude that the total resistance can be divided into frictional and residuary components. The residuary components include the wavemaking resistance, eddy resistance and the interaction between the frictional resistance and these resistance components. The residuary resistance is assumed to be proportionally the same for model and ship at the same value of the Froude number $V/\sqrt{gL}$, but the frictional resistance is a function of the Reynolds number VL/ν and is therefore a key element in any correct extrapolation.

The models must be made to close tolerances. In Fig. 5 the manufacture of a paraffin wax ship model is shown.

The choice of model length is governed by a number of considerations. The larger the model the more accurately it can be made and the larger are the forces to be measured, both features leading to greater accuracy in measuring resistance. However, the larger the model the more expensive it is to build and handle, and the larger the necessary facilities (to avoid bottom and wall effects on the test results) and instruments. Consequently, some compromise in size must be reached. On the other hand, in all model testing care must be taken to ensure that the flow along the model is fully turbulent. Therefore, models should not be made too small and turbulence stimulators need to be added to them.

An important part of ship model research is still focussed on the investigation of scale effects in order to improve the quality of full-scale predictions. In this process, the results of full-scale ship trial tests are indispensable.

Cavitation

The thrust developed by a screw propeller results from the pressure difference between the face or pressure side of the blade and the back or suction side of the blade. When the pressure on the suction side of the blade is reduced below the vapour pressure, vapour-filled cavities will be formed. The existence of cavitation is also influenced by the non-uniform flow in which the propeller blades operate behind the ship.

As the cavities move further along the blade to a point where the pressure increases, they collapse violently. The violent collapse of a cavity is in fact an implosion caused by sudden condensation of the vapour. According to the physical nature of the cavitation, sheet, bubble, cloud, tip vortex and hub vortex cavitation can occur. In Fig. 6 differences in these cavitation phenomena can be seen on a high-speed propeller.

The discovery of cavitation came about through observing the effect it has on the performance of the propeller ; it can cause the rotational propeller speed to increase out of proportion to the applied torque and also lead to a decrease in efficiency.

This phenomenon (termed the "racing" of screw propellers) was the subject of early research and has been studied by many scientists. This is nearly always done experimentally in so-called cavitation tunnels in imitation of Parsons, who in 1895 thus devised an acceptable propeller configuration for his experimental steam turbine ship "Turbinia", which had to operate at speeds in excess of 30 knots. The working section of the Large Cavitation Tunnel at MARIN is shown in Fig. 7. Parsons found that the occurrence of cavitation imposes a limit on the amount of thrust developed per unit area of the propeller blade. Whereas use of such a criterion will avoid the extreme case of propeller racing or thrust breakdown, it was found that more refined criteria were necessary to avoid other consequences arising from the occurrence of cavitation.

One of these consequences is damage to the propeller in the form of erosion and bent trailing edges. It was found that high energy levels are associated with cavitation bubble collapse, which can lead to damage when occurring directly on the blade surface. Intense and persistent erosion will sooner or later result in loss of material or even loss of a complete propeller blade.

With the trend towards higher ship speeds and larger displacements in later ship designs, and accordingly towards higher shaft horsepowers, other detrimental effects of cavitation started to play a role too. These include the noise emitted by a cavitating propeller and the large amplification of propeller-excited hull pressures and shaft forces due to cavitation.

To avoid such detrimental consequences of cavitation, it became necessary to study the behaviour of cavitation experimentally.

In a conventional towing tank no cavitation will occur on the propeller blades, because the ship and propeller are scaled down while the air pressure above the water is kept at constant atmospheric value. In the case of simulating cavitation at model scale, besides the Froude and Reynolds numbers, the "cavitation" number for the model and full scale has to be kept equal. The cavitation number reads :

$$\sigma = \left(\frac{P-Pv}{\frac{1}{2}\rho V^2}\right) \text{model} = \left(\frac{P-Pv}{\frac{1}{2}\rho V^2}\right) \text{full scale}$$

in which P = static pressure ; Pv = vapour pressure ; ρ = density of water. and V = water velocity.

This scaling law means that, if the scaling law of Froude is satisfied, the air pressure must be reduced by the same factor as the geometry. Therefore, for cavitation research, test facilities are needed in which the air pressure can be lowered. The need for such a facility was first recognised by Parsons, and in 1895 he built his first so-called cavitation tunnel.

A cavitation tunnel consists of a vertically placed closed water tunnel with a free surface in a dome in which the air pressure can be lowered. The water is circulated by a screw pump in the underleg of the tunnel. Cavitation can be observed through windows placed in the side of the tunnel. The large cavitation tunnel at MARIN was put into operation in 1948.

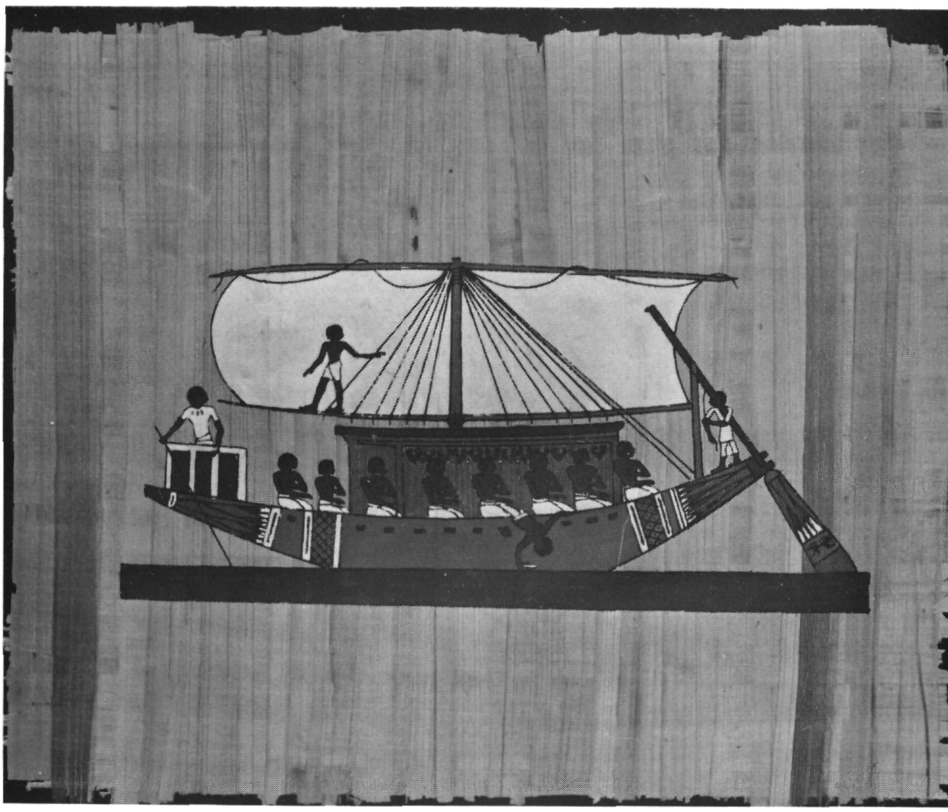

Fig. 1. — Indication of water line on ancient vessel.

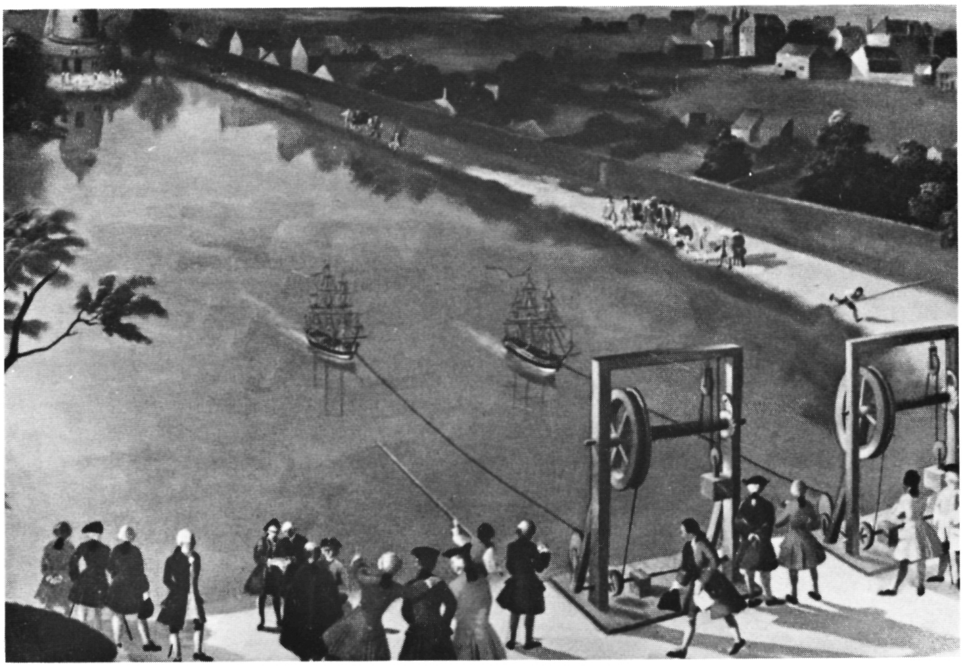

Fig. 2. – Painting of Anna Zinkeiser of model testing in St. Catherina's Dock, London.

Fig. 3. – The stern wheel cruise vessel "Mississippi Queen" in operation on the Dutch waterways..

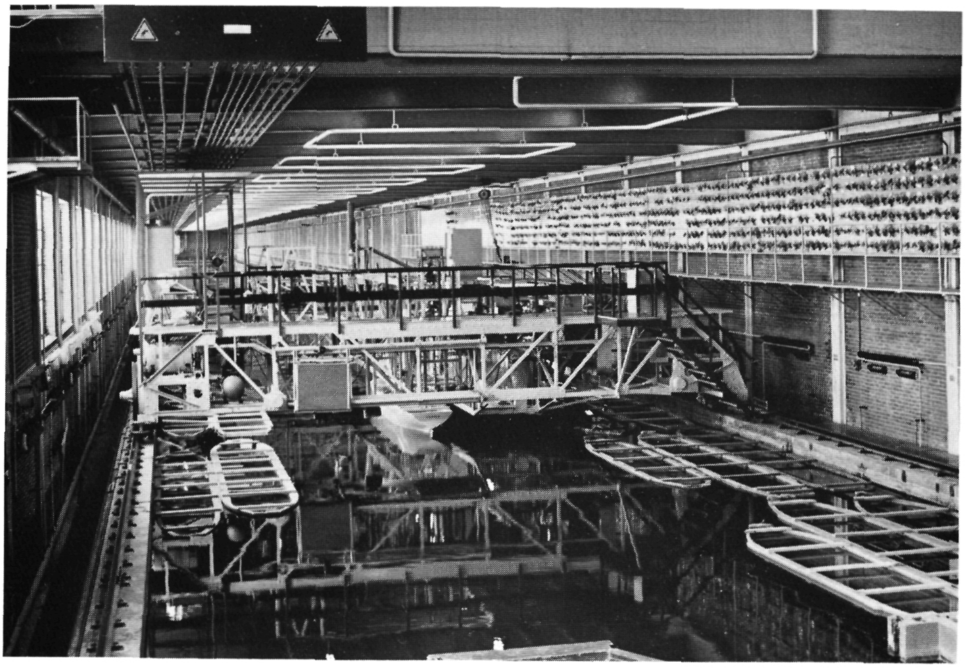

Fig. 4. — Overview of the Deep Water Towing Tank of MARIN.

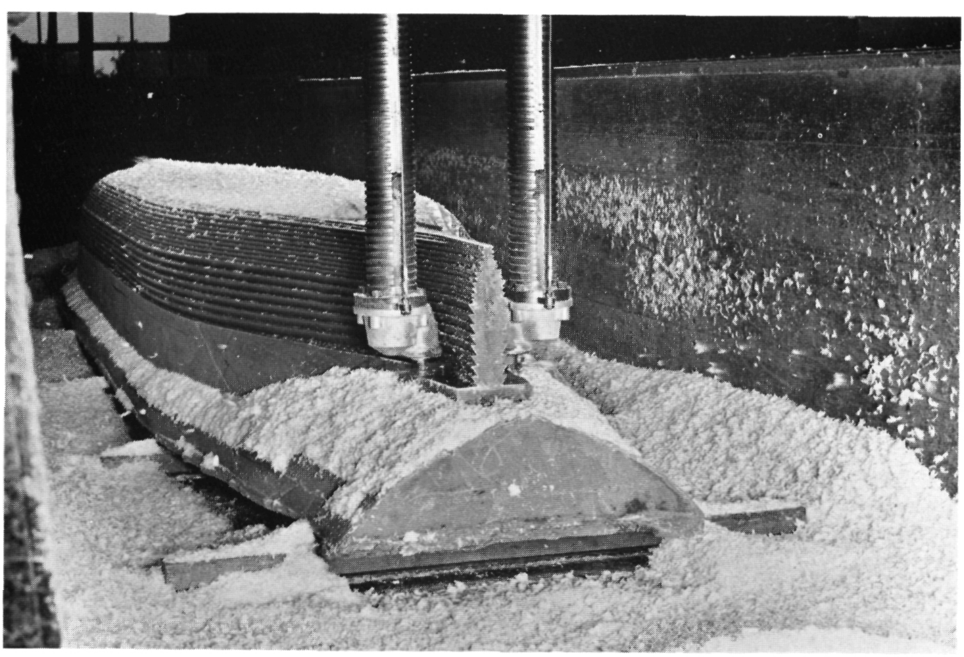

Fig. 5. — Manufacture of a ship model.

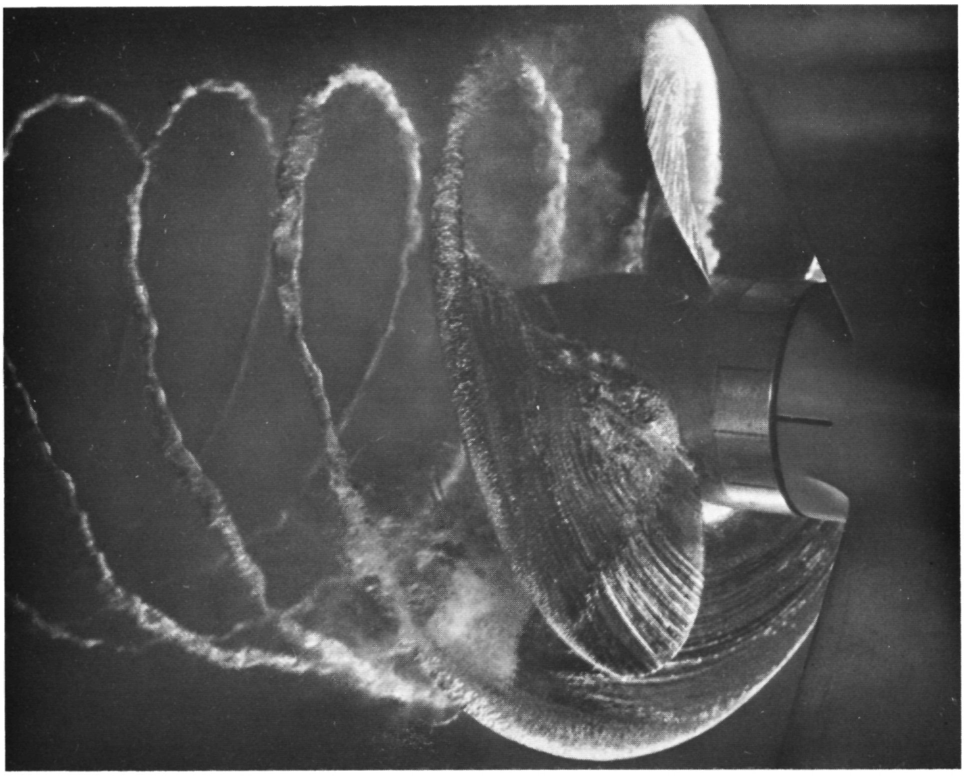

Fig. 6. — Cavitation phenomena on a screw propeller.

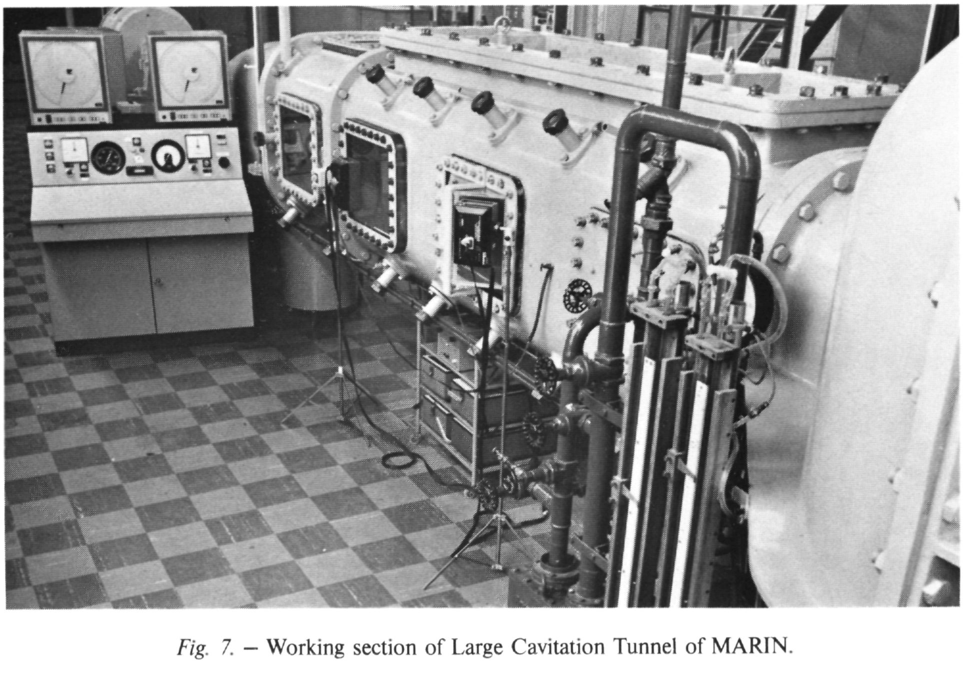

Fig. 7. — Working section of Large Cavitation Tunnel of MARIN.

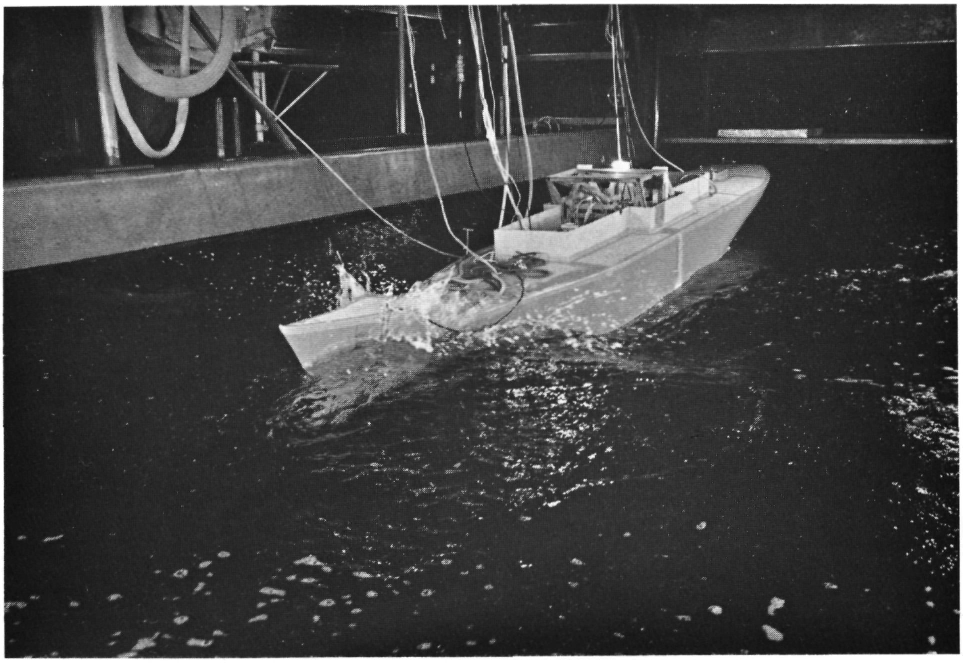

Fig. 8. – Ship model in oblique waves in the Seakeeping Basin of MARIN.

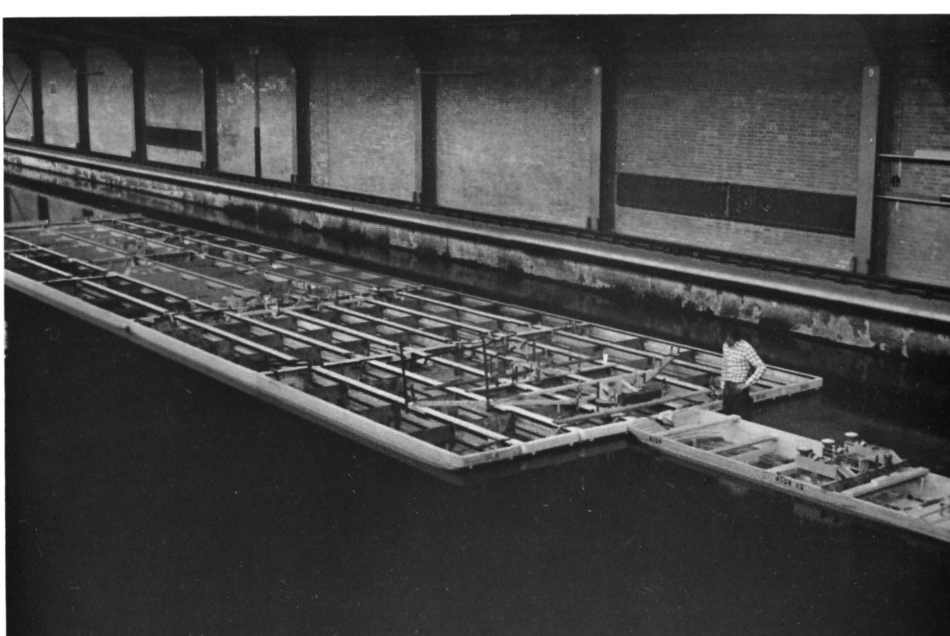

Fig. 9. – Push boat with barge fleet in the Shallow Water Basin of MARIN.

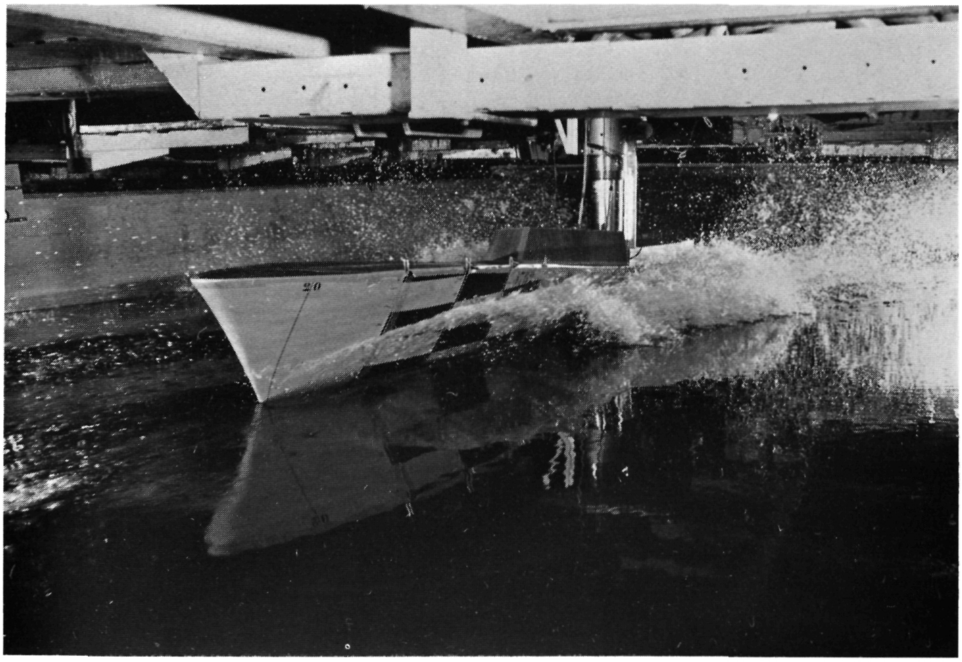

Fig. 10. – Fast deplacement ship in the High Speed Towing Tank of MARIN.

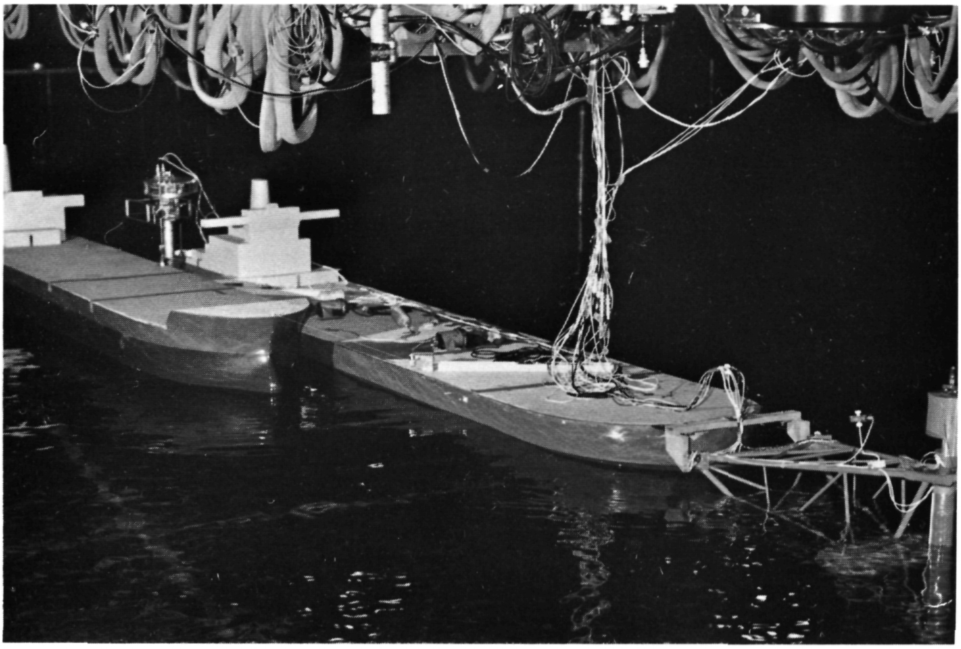

Fig. 11. – Mooring system with storage tanker and shuttle tanker in the Wave and Current Basin of MARIN.

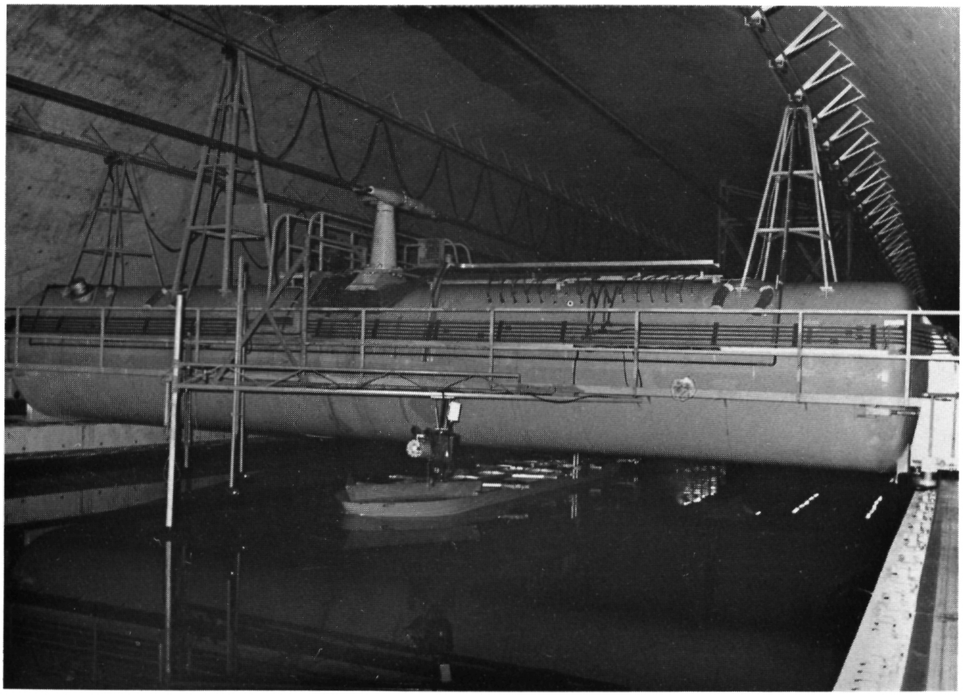

Fig. 12. — Ship model under towing carriage in the Depressurized Towing Tank of MARIN.

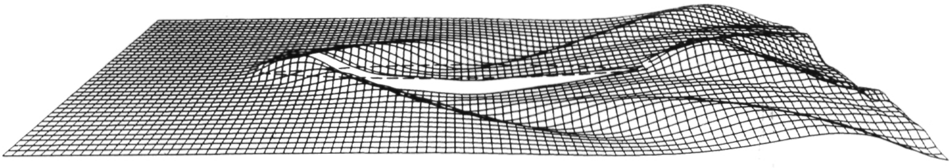

Fig. 13. — Wave pattern of a ship calculated with DAWSON.

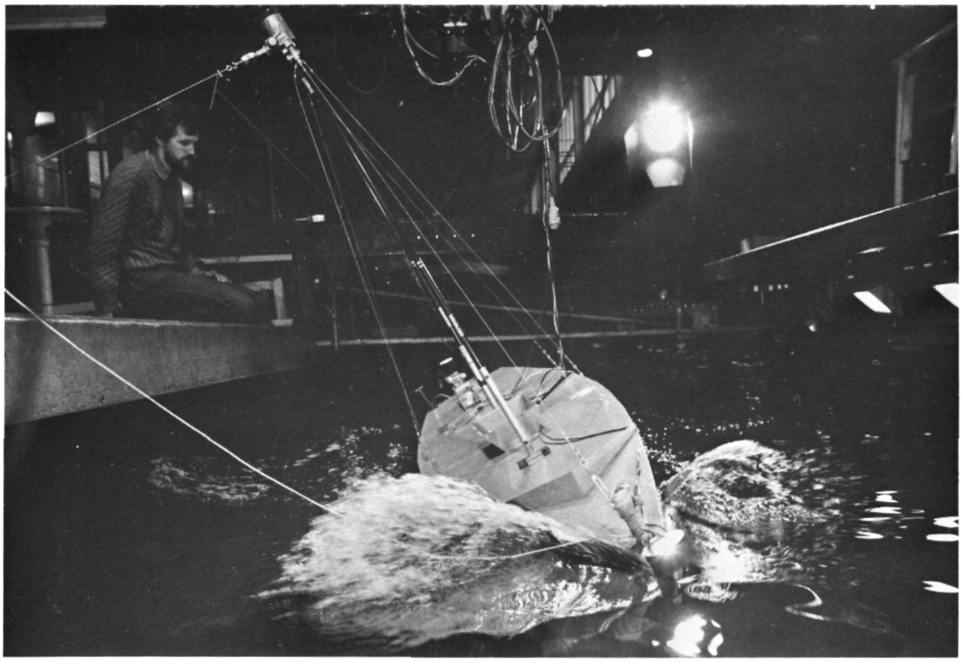

Fig. 14. — Test set-up for the optimization of sailing yachts.

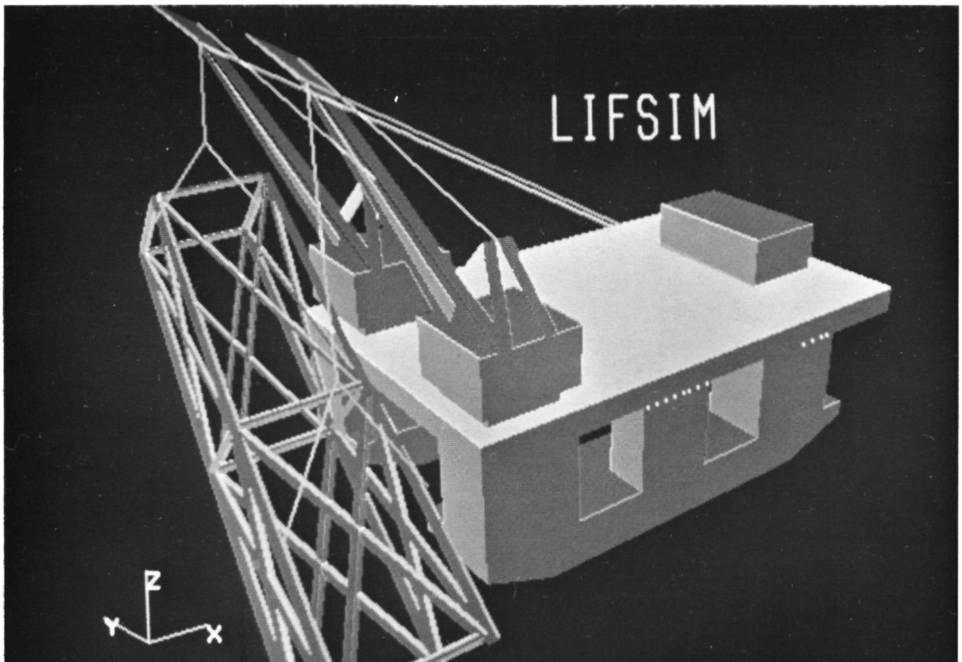

Fig. 15. — Crane vessel "Hermod" with liftable jacket as model for the computer program LIFSIM.

Extension of test facilities in the last 50 years

In the period from 1900 to 1950 the size and dimensions of ships did not change much, though there was an increase in speed from about 12 knots to 16-20 knots.

After 1950 the size of ships, of tankers and bulkcarriers in particuler, increased dramatically and higher ship speeds also became common. In addition there was a sharp diversification in ship types, including container ships, Ro-Ro ships, car ferries, etc.

In 1960 offshore or ocean engineering activities started, focussing on the exploration and exploitation of minerals in the seabed. For this reason floating and fixed structures had to be developed, which required applied scientific research. Moreover, many auxiliary vessels such as supply boats and anchor-handling tugs had to be developed. Also of great interest was the development of (single-point) mooring systems at sea.

After the increase in oil prices around 1970 and the subsequent oil crisis growth in the size and speed of ships came to a full stop. Energy saving considerations started to influence the design of ships and propellers in particular. For the offshore and ocean engineering industry there was a growing interest in cheaper means of explorating and exploitating the seabed. Over the last few years there has also been growing interest in advanced high-speed ships.

Until 1950 applied hydrodynamic research for ships focussed mainly on the optimization of hull form and propeller by means of model tests in towing tanks or deep water basins as well as by tests in cavitation tunnels. The Netherlands Ship Model Basin (NSMB) was founded in 1929, and work started in Wageningen in 1932. Later the name of NSMB was changed to MARIN, which has the following facilities at its disposal:

– Deep Water Basin (1932)

In this tank, ship models up to 8 m in length can be tested in still water. This tank was and is mainly used for resistance and propulsion tests, determination of wake flow (for propeller design and to judge the aftbody of the ship), and "open-water" or free-running tests with screw propellers.

– Cavitation Tunnel (1941)

In this tunnel, having a test section with a cross-section of 0.9 × 0.9 m, screw propellers with a maximum diameter of 40 cm can be tested. Cavitation tests on propellers and profiles in various types of flow can be carried out.

Although MARIN was certainly not one of the first model basins in the world, it has had a great influence on the developments that have taken place since 1950. Owing to the trends in ship design mentioned at the beginning of this section, the scope of ship research was widened. Naval architects came to the model basins with questions concerning the behaviour of a ship in a seaway, the effect of shallow water on the performance of a ship, propeller cavitation in relation to unsteady loads on hull and propeller shaft and to noise, and also the manœuvring characteristics of ships. In addition, the offshore industry came to the model basins with its particular problems.

To answer such questions and assist in solving problems a number of special-purpose laboratories were built. Thanks to the way MARIN is operated and the institute's industrial (and international) orientation, most of the facilities built there after 1950 were the first of their kind in the world.

These facilities include :

– Seakeeping Laboratory (1956)

In this facility regular and irregular waves from different directions can be generated. The facility is used for ship motion measurements, speed loss in waves or the required power to maintain speed, hull pressures, slamming, shipping water and screw racing. Furthermore, wave-induced shear forces, bending and torsional moments can be measured. These measurements can also be carried out for floating and fixed offshore structures. Fig. 8 shows a ship model in oblique waves in this facility.

– Shallow Water Basin (1958)

In this facility the water depth can be varied. Resistance and propulsion tests in shallow water can be carried out, and squat and trim measurement taken. Manœuvring tests with ships can be carried out owing to the large size of the basin.

The basin is equipped with a wavemaker, which makes seakeeping tests in shallow water possible.

The basin is used particularly for optimizing push boats and barge fleets on the Mississippi (see Fig. 9) and the river Rhine, as well as for determining motions, mooring and anchor-line forces of semi-submersibles or moored structures.

– High-Speed Towing Tanks (1965)

This facility has two towing carriages that can run at maximum speeds of 30 and 60 knots respectively. The basin also has a wavemaker.

The testing of high-speed ships (see Fig. 10) and high-speed propulsion devices takes place mainly in this facility.

– Wave and Current Basin (1965)

In this facility regular and irregular waves from different directions, a current or tide flow, wind and the effect of a limited water depth can be simulated.

Determining the feasibility of vessel configurations with respect to waves, current and wind, and in shallow or deep water takes place. Many mooring systems have been optimized in this facility, where manœuvring tests with ships are also carried out. In

Fig. 11 a mooring system with storage tanker and shuttle tanker is shown during tests in this facility.

– Depressurized Towing Tank (1972)

The Depressurized Towing Tank is a water basin measuring 240 × 18 × 8 m. The complete towing tank can be closed airtight. The air pressure in the tank can be adjusted between the actual atmospheric pressure and a minimum pressure of about 4 kPa. By adjusting the air pressure according to the Froude scaling, many kinds of experiments related to cavitation can be carried out with propellers fitted behind large ship models. So both the Froude and cavitation number are equal to those at full scale. Ship models up to 13 m in length can be tested ; propeller models have diameters of 30 to 35 cm.

In this absolutely unique facility, resistance, propulsion and propeller cavitation tests can be carried out (see Fig. 12). The interaction between propeller and ship hull, and the effect on propeller cavitation is taken into account. Further, flow visualization tests, observation of wave-breaking phenomena at the bow, wake surveys, propeller-induced vibratory forces in shaft and on hull, and acoustic measurements can be made.

Two other facilities which MARIN has available are an Outside View Simulator for training or ship handling, the development of navigational aids, the design of harbour entrances and for the development of criteria for manœuvring, and a Vessel Traffic Simulator for research and for training of VTS operators and traffic controllers.

Other facilities which have been developed are Very Large Cavitation Tunnels, Basins for Testing Ships in Ice and Rotating Arm Facilities for manœuvring tests.

A large number of model basins of the types mentioned are still under construction all over the world.

Impact of numerical computations on hydrodynamic research

After 1970 the hydrodynamic research carried out in ship-model basins started to be influenced by the use of computers. Rigorous computer and mathematical simulation programs are becoming available, making it possible to tackle problems that were formerly impenetrable. In addition, advanced measuring techniques have been developed which are used in combination with the computer programs and increase the accuracy of measurements. For an evaluation of these computer programs special measurements are required in a number of cases.

Computer programs were or are under development that can be used in the design of ships, enabling a rapid assessment to be made of the behaviour of ship and propeller for various alternative geometries. Use is also made of statistical methods to predict the propulsive performance ; strip theory calculations to predict the ship motions ; lifting surface theory to design and analyse propellers regarding propulsion, cavitation, hull pressure fluctuations and dynamic shaft forces ; finite element calculations to check the strength of propellers and mathematical manœuvring models. For the offshore industry special programs have been developed including the calculation of wind and current forces, mean- and low-frequency wave drift forces, time domain simulation of moored floating systems and the dynamics of anchor lines.

The most important application of computer programs is in the optimization phase of the design process. In a short period of time many alternative hull forms or other floating or fixed structures can be investigated and their relative merits determined. The form that proves to be the best on the basis of such a series of calculations is the one from which a model can be made for tank testing to otbtain absolute data.

By way of example, the MARIN computer program DAWSON may be mentioned. This program is an advanced and powerful computer tool in the design of ship's hulls. It consists of calculating the potential flow along a ship's hull, as generated by a large number of source panels covering both the hull and the free water surface. The source strengths, and thus the velocities and pressures at all desired points, can be calculated from a set of equations that represent the boundary conditions imposed on the hull and the free surface. The wave and other forces then follow from an integration of the pressure along the hull. From the resulting vertical forces on the hull the dynamic trim and sinkage are predicted. The wave pattern of a ship calculated with DAWSON is shown in Fig. 13.

Another feature that has been added to this program is the possibility of including lifting surfaces, such as stabilizer fins, foils for manœuvring and attitude control for SWATH vessels, for instance, winged keels for sailing yachts, flow control ducts at the afterbody, etc. The effects of the forces generated by these lifting surfaces on the flow along the hull, and of the waves generated by the moving hull on the lifting surfaces, are in this way taken into account in a single calculation run. In Fig. 14 the test set up to optimize sailing yachts and evaluate the computer programs is shown.

Another example is the MARIN computer program LIFSIM, standing for the simulation of Heavy Lift Operations. This program can be used to investigate the behaviour of a large heavy crane vessel, a transportation barge and a load being lifted by the crane vessel from the barge. In Fig. 15 crane vessel "Hermod" with liftable jacket as LIFSIM model is shown.

Although computer programs are becoming powerful tools in the design and operation of ships and other floating structures, it is still expected that in many cases model tests will remain indispensable. The accuracy of computer calculations (with their physical simplifications) are such that a check on absolute values is needed. For a number of problems, particularly where extreme or survival conditions are involved, no computer programs yet exist.

Final remarks

The ocean can contribute in a significant way to the ever-increasing demand for transport, the solution to the problems of world starvation and to the world's need for energy and materials. However, the sea is a hostile environment, and the problems of working in it have presented man with challenges that in the past and more recently have strained the ingenuity and engineering skills of our research workers and scientists to the limit.

Great developments have taken place in model testing techniques and prediction methods since the ship model tests of William Froude and the cavitation tunnel tests initiated by Parsons. Many test facilities are nowadays in operation and the work area has been extended. Nevertheless, the sea – always the same yet always different – still holds many unsolved problems for research workers. The ultimate goal of their work remains the same, namely to help promote the safe and responsible use of the oceans by means of ships and other floating or fixed structures.

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