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THE DAVID W. TAYLOR MODEL BASIN

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A Review of Developments and
Research at the Hydromechanics
Laboratory of the David Taylor
Model Basin, 1953-56

by
Dr. F. H. Todd
Chief Naval Architect

For Presentation to the 11th
American Towing Tank Conference,
held in Washington, D. C.
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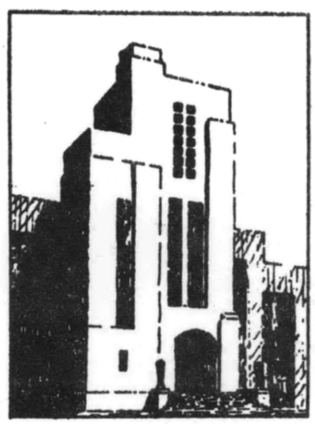

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Meetings of the American Towing Tank Conference take place every three years, and so provide a suitable opportunity for reviewing the developments in facilities, equipment and instrumentation at the different establishments, and also for a brief survey of some of the research projects being carried out.

The last such survey of the Hydromechanics Laboratory at Taylor Model Basin was presented to the Conference held in Cambridge, Massachusetts, in May, 1953.

The great increase in activity in the Navy programs in recent years has led to a heavy load of test and development work in connection with new ship designs and conversions of existing ships, and this situation continues to dominate the efforts of the Laboratory. Much of this work is of direct interest to the Navy only or is of a classified nature, and it is necessary to emphasize that the work described here represents only a small part of the Laboratory's total effort.

The past three years have been noteworthy for the progress made in the provision of much-needed facilities so that the Model Basin will be able to continue to fulfil its basic mission to the Navy and the country in the field of hydromechanics. These facilities and some of the new instrumentation will be briefly described. Further details will be found in the papers presented by staff members to the technical sessions of the Conference and in Taylor Model Basin reports.

Facilities

Model Manufacture

As described in 1953, the use of wax models has been brought to the stage of routine production, and with added experience the time and cost of manufacture have been further reduced. Progress has also been made in the use of glass-reinforced plastic models, which are very much lighter than either wood or wax models, and extremely useful in cases where small models have to be used fitted with extensive measuring and recording gear.

36-Inch Variable-Pressure Water Tunnel

The two presently existing tunnels at TMB have for long been very much overloaded with work, and moreover are inadequate for modern needs as regards the size of propeller which can be tested, the provision of adequate power and revolutions per minute and the very desirable feature of a low noise background. Plans for a new tunnel were started in 1945, designed to give much quieter operation, to provide the possibility of using either upstream or downstream propeller shafts, as occasion demanded, or both shafts at the same time to enable tests to be run on contra-rotating propellers. In order to give adequate control over the air-content of the water, the tunnel will have a deep resorber in the circuit. Alternate closed- and open-jet measuring sections will be provided, each 36 inches in diameter, and the maximum water speed will be 50 knots.

During 1954 and 1955 an intensive review of the design was carried out, and specifications drawn up for the necessary instruments. Some contracts were placed for electrical equipment in 1953 and the final contract for the tunnel itself and the associated buildings was let in December, 1955, the completion date being February, 1958. Work commenced immediately, and at the time of writing excavation of the 70 ft. deep resorber pit out of the solid rock is nearly complete and some of the foundations for the tunnel and building are being laid.

A detailed description of the tunnel will be presented to the Facilities session of the Conference.(1)

Rotating Arm and Maneuvering Basin

The increase in speed of submerged submarines has brought in its train many problems concerned with the directional stability and control of such craft. A submarine "flies" in an atmosphere which has a depth of only a little over two ship lengths (from periscope depth to maximum operating depth) and the additional problems and dangers introduced by a three-

(1) See list of references on page 24

fold increase in speed can be readily realized. In order to cope with these, the mathematical theory of directional stability has been developed very rapidly in recent years. Its application to the prediction of ship behavior requires model experiments to determine certain coefficients for any particular design, which have then to be inserted in the equations of motion. Some of these coefficients, the static derivatives, can be obtained from experiments in which the model is run on a 3- or 6-component dynamometer on a straight course at different angles to the flow, the lift, drag and moment being measured. To obtain the rotary derivatives, the most satisfactory method is to make the model execute circles at different radii and at different drift angles, measuring the resultant forces and moments.

Such experiments can be carried out on the rotating arm at Stevens Institute, using comparatively small models, and at the Paris Tank, where 20 ft. models can be used but only at comparatively low speeds and Reynolds numbers. A large facility of this kind is presently being built at the Admiralty Experiment Works, Haslar, and the need for a similar one at TMB has long been felt. A functional specification and an outline design were prepared at TMB in 1951, comprising a circular basin 260 ft. in diameter and 20 ft. deep, with a rotating arm mounted on a central island and driven by wheels on a peripheral rail. The arm is designed to carry a 20 ft. submarine model 10 ft. below the surface, or a 30 ft. surface ship model, up to a maximum radius of 120 ft. The maximum steady speed at 120 ft. radius is to be 50 knots in less than 2·1/2 revolutions.

The modern trend towards increased speeds in both merchant and naval vessels has placed great emphasis upon good sea-keeping qualities. It is of little use increasing the smooth water speed by fining the hull form and providing more power if the behavior in a sea is poor and results in no appreciable increase in average sea speed. Analysis of log and other data has shown that in general ships are slowed down deliberately because of violent motion rather than involuntarily by actual lack of power, and so interest has been directed towards reducing the motions of ships in a seaway. This work has obvious bearing also on a number of naval problems such as the landing of aircraft on carriers, missile-launching and the pursuit of high speed submarines by surface craft, model work on all these problems has been greatly handicapped in the past by the inability to carry out tests in anything other than head or stern seas.

In 1951, when the Model Basin first drew up specifications for a facility in which models could be run at all angles to regular or irregular seas, no other such facility existed anywhere. In the intervening years other nations have designed similar installations, that in Holland having been opened in May this year and the one at AEW, Haslar, being well forward in construction.

The TMB maneuvering or seakeeping basin will be 360 ft. long, 240 ft. wide and in general 20 ft. deep. Pneumatic wavemakers will be fitted along two adjacent sides and beaches on the others. The wavemakers will be able to produce regular waves from 3 to 40 ft. in length with a maximum height of 24 in. It is hoped to fit individual controls on the 8 sections of the wavemaker along the short side so that irregular seas, both long- and short-crested, can be generated to fulfil all reasonable wave spectra.(2)

For convenience both the rotating arm and the maneuvering basin will be housed in a single building. The consulting engineers are Sverdrup and Parcel, who prepared the bidding plans and specifications, and the contract was let in May, 1956. Work of clearing the site began immediately and the completion date is November, 1958. The facilities will be at the extreme west end of the site and will be a notable addition to the equipment of the Model Basin.

Wavemakers

In order to provide for tests of self-propelled 20 ft. models in waves, a pneumatic wavemaker was built at TMB and installed in the large basin in 1955. It spans the 51 ft. wide basin, in which the water depth for wave experiments is reduced from 22 ft. to 19.5 ft. in order to clear the side wave dampers.

It can generate waves from 5 to 40 ft. in length with a maximum height of 24 in., and has proved very successful.(3) It is built in two sections, each of which is in fact a prototype of the units to be installed in the new maneuvering basin, so that operating experience is being obtained which can be used to ensure that any modifications found necessary can be incorporated in the new wavemakers.

Wave Absorbers or Beaches

Extensive research has been carried out by the St. Anthony Falls Hydraulic Laboratory, University of Minnesota, under contract with the Basin, to determine the most efficient form of beach to install in the new maneuvering basin. A type consisting of layers of square bars, prefabricated in concrete sections, was finally selected, and a full scale beach of this type has been installed in the large basin at the end opposite from the new wavemaker. It has proved very successful.

Instrumentation

Rotating Arm and Maneuvering Basin

The basic design of the testing equipment for the rotating arm and maneuvering basin has been completed, this being a joint effort of the consulting engineers, the Industrial Department of the Basin and the Hydromechanics Laboratory. The instruments are intended to measure and record forces, moments, model attitudes, carriage and arm speeds and many other quantities. In order to assist in defining the measurement problems which will be met in a basin in which various types of seas will be generated, a 1/10th scale model has been built. It is 36 ft. long, 24 ft. wide and the water depth is 2 ft., and is complete with multiple pneumatic wavemaker units and wave absorbers of the type which will be used in the full size facility. The performance of the model has been encouraging and valuable information has already been obtained from its use.

Improvements to Carriages

Instrumentation

Special instrument systems have been designed for use for tabulating and handling data during tests, including a graphical recorder system, a revolutions-speed-time recorder and an automatic digital indicator. Some portions of this instrumentation have been completed and are in use, and studies are underway to make permanent console-type installations on all carriages. A console incorporating all the necessary controls and indicators for model turning tests has been installed on Carriage I for use in the J Basin.

Improvements have been made in the precision of the speed control on Carriage 5.

Shallow Water Towing Equipment on Carriage I

A new towing girder has been designed and built which is adjustable in vertical position so that models can be towed in the shallow water basin for all depths of water up to the maximum of 10 ft.

Rubber-tired Wheels for Carriage 5

In order to obtain a quiet-running carriage for acoustic work, Carriage 5 has been equipped with water-filled rubber-tired weight-carrying driving wheels and solid-rubber-tired guide wheels. A survey of the vibration and motions of the carriage on the rubber tires was carried out for all basic modes from 12 to 55 knots. The only modes for which measurable amplitudes could be detected were in pitch and heave.

Hydrofoil Balance

A five-component force and moment balance has been built which measures lift, drag, side force, rolling and pitching moments on full scale hydrofoils for small craft. The sensing elements are special flexures fitted with resistancewire strain gauges, giving ranges of:

Lift	0 - 5,000 lbs.
Drag	0 - 1,000 lbs.
Pitch Moment	0 - 63,000 lbs.in.
Roll Moment	0 - 68,000 lbs.in.
Side Force	0 - 1,500 lbs.

Submarine Simulator

The simulator consists of a control cabin mounted on a single-axis tilt table which simulates pitch of the submarine. The cabin contains two control positions, each equipped with a joy-stick type control, and furnished with the necessary instruments and indicators. The motion of the control cabin is governed by an electro-hydraulic servo-system receiving inputs from an analog computer. In use this cabin constitutes one link in a complete submarine simulator. The equations of motion of a given type of submarine are set up on the Reac computer, the various coefficients appropriate to the boat having been determined by model test and calculation. When the boat is subject to rise and dive maneuvers by a movement of the joy stick in the control cabin, the computer calculates the resultant path and attitude of the submarine. This information is relayed to the cabin, where the angle of trim and depth are shown on the indicators and the cabin takes up the correct pitch attitude. At the same time a graphical record is automatically plotted of the submarine's path.

By changing the coefficients in the equation of motion on the computer, the effects of changes in control surfaces and other items can be quickly obtained and their tactical value evaluated. A submarine can be made to perform any maneuvers in the vertical plane, some of which would be too hazardous to attempt in reality at sea, and new ideas of revolutionary character can be explored. The simulator has proved to be a valuable tool also for evaluating the reaction of personnel in manual control of submarines and for providing information for the design of automatic control systems.

Dynamometers

Propulsion Dynamometers

Four 5 horsepower transmission-type dynamometers have been developed specifically for use in self-propelled tests on small models of high speed boats. These dynamometers are extremely compact and measure thrusts up to 60 pounds and shaft torques as high as 40 pounds-inches with maximum rpm of 8,500. They can be driven by any commercial electric motor. With twin screw models, synchronizing gears are used to ensure the same rpm on both shafts. Because of their small size and relatively high power characteristics, these units have also been found useful for submarine and landing craft model propulsion tests.

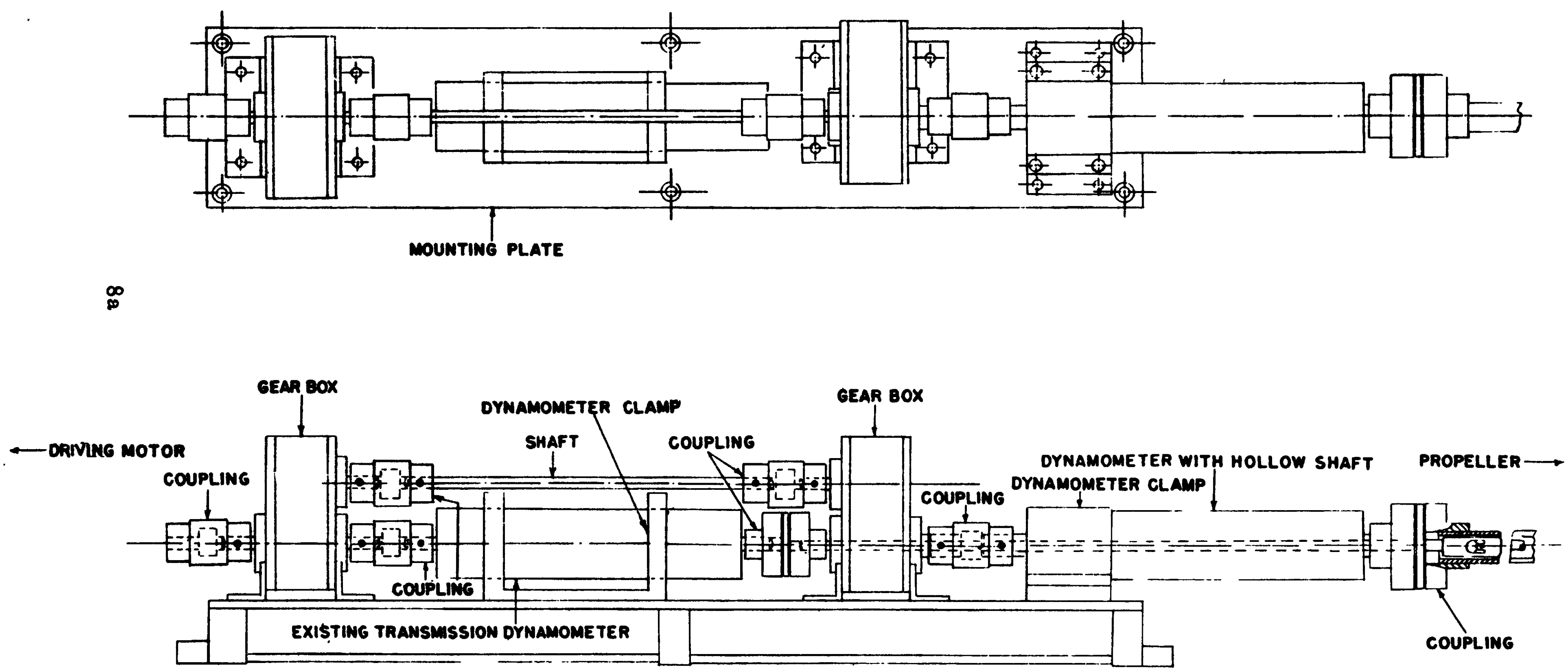
Submarine Contra-rotating Propulsion Dynamometer

The design for this dynamometer has been completed and it is now being constructed. It has a hollow shaft and will use the magni-torque and recently developed magni-thrust transducers. This unit will be used in combination with one of the existing submerged transmission dynamometers, and synchronization will be achieved through a gearing system. The dynamometer will have a capacity of 50 pounds in thrust and 50 pounds-inches torque, recording on two 2-channel Brown recorders or digital indicators.

(See Fig. 1)

Torpedo Contra-rotating Dynamometer

This dynamometer has been built to fit into any full scale torpedo 19 inches or larger in diameter. Each shaft is independently powered by a dual armature motor which is attached directly to the unit. The contra-rotating assembly is mounted in the torpedo and the torque, thrust and rpm of each propeller are telemetered to the operators by the use of magni-gauges and electronic-type revolution pick-ups. Each shaft is instrumented for 300 pounds-feet torque, 600 pounds thrust and speeds up to 3,000 rpm.



SUBMARINE CONTRA-ROTATING DYNAMOMETER ARRANGEMENT

Twin Rudder Dynamometer

A twin rudder dynamometer of the three-component strain-gauge type has been completed. Simultaneous and separate measurement and recording of normal rudder forces up to 60 pounds and tangential rudder forces up to 10 pounds per rudder, as well as 40 pounds-inches rudder torque, can be made. The rudders can be remotely controlled and their positions recorded.

Thrust Variation Dynamometer

A dynamometer has been developed to measure the thrust-vibratory forces of hydrodynamic origin on self-propelled submarine models. This will enable the effects of the design and position of propellers and stern appendages upon possible vibration to be studied and the effects of variations in these features to be evaluated on model scale.

Full Scale Trial Instrumentation

The development has continued of instruments for measuring transient conditions during full-scale maneuvering trials. During the period under review hydro-telegages to indicate and record transient pressures, recorders for transient torque, thrust, rpm, vacuum and selected steam pressures and boundary layer rakes for wake surveys were completed.

Hydromechanics Research Program

This research program covers projects in both basic and applied research, with emphasis in general on the latter category. It is carried out partly at TMB and partly by contract with various universities, laboratories and research corporations.

It is related to similar programs in basic research administered by the Office of Naval Research, and both the latter office and the Bureau of Ships are represented at the meetings of the Laboratory Research Council when proposals for outside contract research are being considered.

About one third of the Laboratory's effort is devoted to the research program.

Resistance and Powering

Surface Ship Design

Work has been continued on the single-screw merchant ship forms designated as TMB Series 60.

The revision of Series 57 was completed in 1953 and the results of resistance tests on the parent models of the new Series 60 were presented to the Society of Naval Architects and Marine Engineers in that year.(4) It was shown that the new parent models compared satisfactorily with those of new successful ship designs and were therefore an adequate basis for developing a systematic series. The same parents were tested in the self-propelled condition and the results given in 1954, showing the effect of propeller diameter, block coefficient, displacement variations and trim on propulsive efficiency and comparisons were made with modern designs of actual ships.(5)

In 1956 the results of experiments with models having the same principal characteristics as the parents but with different positions of the longitudinal centre of buoyancy were completed and presented to the Society of Naval Architects and Marine Engineers.(6) These showed that in general the model with the least resistance was also the one which required least shaft horsepower. The results gave guidance to designers both as to the best position of the LCB for minimum power and also to the penalty incurred by any change from this optimum position which might be necessary because of other design restrictions.

A new set of parents incorporating the lessons learned from the LCB series have been chosen and the effects of variations in length-beam and beam-draft ratios are now being explored by straightforward geometrical variations. This final stage of the Series 60 research is now well in hand, and it is expected that the results will be presented to the SNAME in 1957.

Planing Surfaces

The National Advisory Committee on Aeronautics and the Laboratory have jointly undertaken an experimental investigation of the planing characteristics of a series of related prismatic surfaces which are important in the design of high speed boats and flying boats. TMB has determined the wetted lengths, resistance and centre of pressure for a series of V shaped planing surfaces with a dead-rise angle of 50° (7).

Wavemaking Resistance

Theoretical work in this field has continued both at TMB and under contract at Stevens Institute.

Cataloging of Model Data

When the results of tests on a model of a new ship become available, it is both necessary and desirable to compare them with those for other models of closely similar characteristics. In this way the merits of the new design can be determined and the possible avenues towards improvement explored. In order to expedite the selection of the models for such a comparison, an edge-punched card system has been selected, and sorting can be done rapidly by machine.

Ship Model Vibration Studies

After two years study of propeller vibration forces on ship models, corresponding forces were measured on the SS Gopher Mariner early in 1954. Known forces were applied to the vessel at the propeller location by a vibration generator, and the response of the hull to these forces was measured in order to obtain a response calibration curve. This was done for each of several vibration forces at various rpm.

The response of the hull to propeller exciting forces was then measured during two successive trips to Europe. The vibratory forces experienced from the propeller were then estimated by comparing this response of the hull to these propeller forces with the calibration curves.

Work is now in hand on the model in an attempt to reproduce similar conditions. Many difficulties have been experienced, and a summary of the work was presented to SNAME (8). Since then improvements have been made in the model vibration testing technique by separating the stern of the model from the rest of the hull. This both increases the accuracy of the measurements and greatly reduces the testing time.

The increasing importance of propeller-excited vibration has indicated the need for knowledge of the magnitude of the pressure pulse and distribution of the pressure field produced by the propeller. Measurements were made at TMB of the free stream oscillating pressures with a view to investigating the effects of tip clearance, axial clearance and number of blades. The measured pressures were those occurring at blade frequency and its multiples, and were measured at points in the free stream both ahead and astern of the propeller. The measurements were carried out using a pressure gauge having a maximum range of $\pm$ 0.5 p.s,i. The gauge is excited by a strain indicator using a carrier signal at 5,000 c.p.s. which is modulated by the pressure signal. The demodulated signal from the strain indicator is then fed into a vibration analyzer which is also supplied with a carrier wave from a sine wave generator directly geared to the propeller shaft and rotating at blade frequency or multiples thereof. Through the use of calibration curves it is then possible to determine the magnitude and phase relationship of the oscillating pressures.

Theoretical work in this same field is the subject of a contract with Stevens Institute.

Frictional Resistance

The collection of data from full scale trials has been continued in order to obtain further information on the necessary "roughness" allowance, ΔC_F, in order to correlate ship powers with those predicted from model tests. The general evidence is that modern all-welded ships with smooth commercial paint give values of ΔC_F considerably below the tentative allowance of $+0.0004$ adopted by the American Towing Tank Conference in 1947. TMB data suggest a value around $+0.0001$ to $+0.00015$, and in one case a zero value has been recorded. Evidence from British data suggest a value around $+0.0002$ for vessels with welded butts and some riveted seams and zero for all-welded hulls. These values all apply to predictions using the Schoenherr friction line.

In connection with the work of the Skin Friction Committee of the International Towing Tank Conference, an exhaustive analysis of all available geosim data has been carried out using various existing and proposed friction lines. These results will be considered by that Committee at a meeting in London in July this year, and will be reported to the ATTC at the September meeting (9).

Work has continued on the problem of stimulation of turbulent flow on models, using planks at small angles of attack in order to find the effects of pressure gradient, the areas of laminar flow being defined by chemical methods.

The 150 ft. long cylinder, 6 in. in diameter, for use in skin friction research has been completed, but lack of available manpower has prevented the initiation of any tests.

A review of the methods of extrapolating the viscous resistance of hull forms from model to full scale has been completed and a general logarithmic formula derived from similarity laws (10).

The surface pitot tube technique for determining local skin friction has been extended for boundary-layer flow with adverse pressure gradient (11). This technique will permit of the characterization of the skin friction of any arbitrary shape and is essential for an understanding of the laws governing shear flows.

In order to evaluate the effect of the roughness of different anti-fouling paints on the frictional resistance of ships, a floating-element dynamometer has been completed for use in boundary-layer studies in the low-turbulence wind tunnel. Concurrently, methods of analyzing the geometrical characteristics of rough surfaces have been investigated. In connection with this work, an analysis of the frictional resistances of rough surfaces based on the similarity laws of boundary-layer flow has been completed (12).

The first phase of the full scale trials of the submarine ALBACORE was completed in 1955. In addition to the standardization, tactical and other usual trials, special efforts were made to obtain the actual resistance of the full scale ship. The hull was kept as free of excrescences as possible, welds were ground smooth, and the cold plastic paint applied with care to give as smooth a surface as possible. The vessel was first self-propelled submerged and the propeller thrust measured. The propeller was then removed and the ship towed submerged and the resistance measured. It is believed to be the first time such towing trials of a submerged submarine have ever been carried out. It is hoped that when the analysis is finally complete we shall not only have full scale resistance data to assist in deciding upon frictional formulations and ΔC_F values, but also for the first time a comparison between model and full scale thrust deduction coefficients.

Propeller Design

The theory of lightly loaded propellers has been developed so as to apply to the design of moderately loaded propellers having a finite number of blades and an arbitrary pressure distribution (13). In this work each blade was represented by a "lifting line" along which the circulation was distributed in some desired way. In applying these theoretical methods to actual designs, it is necessary to obtain a more accurate prediction of performance characteristics and to pay attention to those features which will delay the onset of cavitation. It is therefore necessary to take into account the presence of the actual blade sections themselves and their effect upon the flow. The theory for moderately loaded propellers has therefore been extended to include a correction for the presence of the "lifting surfaces"(14). The theoretical basis for the design of contra-rotating propellers has also been formulated (15).

In the experimental field, tests on controllable-pitch propellers having 2 to 6 blades have been run at TMB, covering a wide variation in pitch settings, while MIT under contract have carried out tests on 4 bladed controllable-pitch propellers having modified Troost sections, in which the forces on the blades were also measured (16).

Further development of design methods has been concentrated on improving the simplified propeller theory for use in designing both wake-adapted and open water propellers (17). In connection with this work a re-calculation of the Goldstein functions resulted in a much more accurate prediction of propeller performance (18).

Scale Effect on Propulsion Factors

Research into this subject has been carried on in many model basins all over the world, partly under the aegis of the International Towing Tank Conference Committee. Results of some of the tests were given in Scandinavia in 1954, and showed considerable disparity in predicted shaft horsepower even between models of about the same size (19). One of the principal series has been that on the "Victory" ship models commenced at the Netherlands Ship Model Basin at Wageningen. One large model has been run at TMB for comparative purposes, while Stevens Institute, under a Navy contract, has run small models for the same purpose. The results of the latter tests are to be presented to the Conference in September (20). The Wageningen results have been given to the Institution of Naval Architects in London (21). One of the principal findings of interest in these tests was a very appreciable scale effect on thrust deduction fraction in going from the average 16 to 20 ft. model up to the large 72 ft. model, the largest of the geosim series run by the Dutch Tank. The value of the thrust deduction fraction increased quite rapidly with size, and this would have important effects on the ship resistance deduced from full scale thrusts measured on trial, and also upon the values of ΔC_F so obtained.

Cavitation

Observations on the inception and development of cavitation on model propellers in a tunnel and on the full scale ship show the presence of considerable scale effect (19). Research on this problem of cavitation similitude continues, partly by trying to approach more closely to the ship conditions in the tunnel by the introduction of simulated wakes ahead of the propeller and by better experimental control of air content and more accurate manufacture of propellers.

Theoretical studies of super-cavitating flow have enabled predictions to be made of drag and cavity shapes for slender symmetrical bodies and of the lift, drag and moment acting on arbitrary hydrofoil sections (22, 23).

<u>Hydrodynamic Noise</u>

The theoretical equations for bubble trajectories in variable pressure gradients have been determined (24). This work requires a knowledge of drag coefficients and virtual mass coefficients of air bubbles in a pressure gradient.

Instruments are being developed for the measurement of the air content of water, both dissolved and undissolved or entrained air. The latter makes use of the acoustic properties of entrained air bubbles.

The noise associated with flow phenomena such as cavitation, turbulence, unsteady flow, entrained bubbles and splashing is being studied to determine the flow conditions required for the generation of noise and to establish the intensity and frequency spectra of the noise in terms of pertinent flow parameters.

Theoretical calculations of frequency spectra of sound from cavitation bubbles are continuing. It has been found that the small yet finite compressibility of water has a major influence on the high frequency portion of the sound spectra.

Of interest in connection with cavitation noise and cavitation phenomena in general are some measurements made to determine the influence of air-filled nuclei on the onset of cavitation. The results show that the size of the nuclei in undisturbed water becomes progressively smaller as the water stands for several days so that the negative pressure required for the onset of cavitation becomes progressively greater. Either reducing the dissolved air content of the water or putting the water under hydrostatic pressures of two or three atmospheres causes the water to require a greater negative pressure before cavitation starts.

Controllability

A large amount of the research in this field, although of general interest, is classified because of its immediate application to the control of submarines and torpedoes.

Research has been continued into a series of semi-balanced rudders tested both in open water and on a turning model. Ventilation occurred in open water when the trailing edge of the rudder was too close to the edge of the boundary plate, i.e. in the ship, too close to the transom or the surface.

Under contract, Stevens Institute has continued to carry out turning tests on a model taken from Taylor's Standard Series in order to investigate the effect of variations in appendages such as skegs, propellers, bilge keels and deadwood.

A study has been initiated to investigate maneuvers which can be used as standards to evaluate directional stability and controllability characteristics of surface vessels. Data have been obtained using spiral maneuvers (Dieudonne) and zigzag maneuvers (Kempf) for several unstable and stable ships and models. The data to date have already indicated areas where compromises must be made between turning ability, directional stability and controllability.

When a ship is actually turning, the true angle of attack on the rudder is no longer the same as the rudder angle measured from the original zero position. An experimental investigation of the velocity and direction of flow in the vicinity of the rudder of a free-turning model of a typical multi-screw ship has provided data which may be used as criteria in designing such rudders (25). An experimental investigation of the effects of varying linkage ratio and flap area on all-movable flapped rudders has shown that a lift coefficient which is 50 per cent greater than that of an equivalent spade rudder can be realized with a 30 per cent flap using a 1.5 flap-linkage ratio (26).

The usual methods for computing the pressure distributions over control surfaces of different shapes and sections are not suitable for computation on the Univac. A new method has been developed which permits such computations to be made, and is being used to develop a systematic series of sections to determine which ones are most suitable for producing lift without cavitation (27).

Hydrofoils

The Model Basin has continued to work on the problems of hydrofoil boats, and has conducted full scale trials on a number of such craft. Recently the Basin was represented on a team from the Navy which went to Eruope to witness trials on new German and Italian boats of the surface-piercing foil type.

The new hydrofoil dynamometer has been used to test various designs of foil for specific application.

In the research field, tests have been conducted on a hydrofoil configuration in waves in order to compare experiment and theory, with special reference to the behavior in following seas.

There is a need for knowledge of the lift, drag and moment characteristics of foils under cavitating conditions, both for hydrofoil boat and propeller design problems. Under contract to the Basin, tests on a series of 2-dimensional foil sections are being run at Iowa Institute, and at California Institute of Technology both experimental and theoretical work are in progress aimed eventually at formulating methods whereby foils can be designed to give any desired characteristics.

Ship Motion Studies

There has been much activity in this field, and that of seaworthiness generally, throughout the years under review.

The ITTC Committee on this subject has carried out comparative tests in waves, using models of the 0.60 block coefficient Series 60 design, in a large number of tanks. The results were given to the Conference at its meeting in Scandinavia in 1954, and were very discouraging (19). As a result a small panel of the ATTC Committee on Seagoing Qualities was appointed to carry out comparative tests in American tanks using a 5 ft. model of the Series 60 design. It was hoped that by paying attention to the techniques of testing and eliminating all possible differences in these matters, satisfactory agreement might be obtained. Results of this study will be reported in detail to the Conference in September (28).

Since the Wageningen Tank, the Admiralty Experiment Works and TMB are all building sea-keeping basins, it was considered desirable that some joint correlation tests should be carried out at these three establishments. TMB accordingly proposed that these should be carried out using a 10 ft. model of the 0.60 block coefficient Series 60 model, self-propelled, and offered to build the model and send it in turn to Wageningen and Haslar. This offer was accepted by both these establishments. The model is of glass-reinforced plastic, and is fitted up with shafting, propeller, dynamometers, and all necessary ballast. In this way it is ensured that any differences in the results will arise from the techniques used at the three establishments or from differences in the waves generated, and not from the use of individual models and propulsion gear. An observer from TMB will be present at the tests in England and Holland so that any differences in techniques can be observed and discussed. The model was tested at TMB earlier this year and was shipped to Wageningen in June.

Since the square basin at Stevens Institute is now being modified to be a sea-keeping facility, no doubt similar correlation tests will be carried out there, but a smaller model will be necessary in that case.

Work has been continued, both in the theoretical and experimental fields, on the forces and moments experienced by streamlined bodies near the surface when the latter is disturbed by regular waves.

Experimental work has been carried out at the University of California into ship motions in uniform and short-crested seas, and the Colorado Agricultural and Mechanical College has made tests with small models at different angles to regular waves in order to get preliminary information upon the instrumentation problems which TMB will meet in the equipment of its new maneuvering basin.

A joint project between New York University and TMB has covered a statistical enquiry into the motions of a ship in a confused, random sea, and Woods Hole Oceanographic Institute has attempted an experimental verification using a launch as the ship and stereophotography to define the state of the sea surface.

Work under contract has also continued at Stevens Institute, where both theoretical and experimental research into ship motions has been continued at a high level. A noteworthy development has been the provision of a wavemaker which can generate an irregular sea which is yet repeatable on successive runs.

A new and useful technique for the investigation of the equations of motion of a vessel in a seaway is under development at TMB, using the pitch and heave oscillator. This instrument forces the model to oscillate with a known motion, and the forces and moments required to generate this motion are measured. The coefficients which appear in the equations of motion can be computed from these data.

Experimental and theoretical studies of hydrodynamic impact upon the water surface have been followed by calculations of the slamming pressures and accelerations for an actual ship under assumed artificial smooth water slamming (29,30,31). An attempt has also been made to compute the pressure distribution on the bottom of a ship slamming in waves, which represents the first approach to the actual slamming problem. A summary of the results was given to the 7th ITTC in 1954 (19).

Combining motion studies with impact considerations leads to a reasonable explanation of the phenomena and furnishes a method of predicting slamming (32,33). The method developed to compute the pressure distribution for the special case where slamming is due to pure pitching has been applied to determine the effects produced on the pressure and its distribution by changes in the shape of the transverse sections. The five parents of Series 60 were chosen as the basis for this study, which shows the effects upon the time and space distribution of the impact pressures of changes in block coefficient from 0.60 to 0.80 (34).

The theory of roll damping has been investigated using three models of constant section shape having beam to draft ratios of 2.0, 2.5 and 3.5. This work is only for 2-dimensional hulls (constant cross section) and includes no effect of bilge keels. At the low frequencies used in the tests, the viscous effects were much more important than the wave effects, while eddy damping was of the same order of magnitude as the frictional damping.

Full Scale Seaworthiness Trials

The use of experiments on models in smooth water as a means of comparing the relative merits of different hull shapes and for predicting the full-sized ship resistance and power is now some 80 years old. Nevertheless, the correct means of carrying out this prediction is still one of the most debated subjects in naval architecture and one which never fails to provoke claim and counter-claim. In the last analysis it must be agreed that we still rely upon some correlating factor to reconcile the model and ship trial results, whether it be some unknown allowance included in Froude's skin friction coefficients for varying ship length or the so-called "roughness" factor, ΔC_F, used in conjunction with the Schoenherr method. In view of this long history of the search for smooth-water correlation, it is obvious that, with the increasing emphasis on ship motions and resistance in waves and the prospect of new facilities coming into commission very soon in which models can be tested in regular, irregular and short-crested seas and at all angles to the waves, we are going to be faced with what may be a similarly difficult and intractable problem.

In order to solve it, both model and full scale data are necessary, and in order to avoid any unnecessary delay, TMB decided to go ahead collecting full scale information at sea while the model facilities are building. The full scale data can be analyzed, and then those tests which are found to be complete and reliable can be simulated in the model and correlation problems studied. This is much more economical in time and money than running model tests first and running the risk that the conditions assumed can never be reproduced at sea.

In cooperation with the Maritime Administration, two Liberty ships have been instrumented for such seagoing service trials. One of these, the "Benjamin Chew", has the original Liberty hull, but new engines capable of developing some 6000 horsepower. The second, the "Thomas Nelson", has a lengthened and much finer forebody, with the same increased power. Instruments have been installed on both ships to measure shaft horsepower, ship motions, hull stresses at one section and the state of the sea. The latter will be done by two sea-state meters designed and built by the National Institute of Oceanography in England and purchased by TMB. It is expected that these two ships will both operate in the North Atlantic in the coming winter, and both the Maritime Administration and the Model Basin will have observers on board. If the trials are successful, a wealth of information will be available on which to base a program of model tests to study the correlation problem.

Similar data have recently been obtained in the course of a joint venture between the U. S. and Dutch navies, in which sea trials were carried out on three different types of Dutch destroyers operating in company in the Atlantic. TMB provided much of the instrumentation and some of the operating personnel, and the results of these trials are now being analyzed.

Conclusion

This survey has given a review of the developments in hydromechanics facilities and instrumentation at Taylor Model Basin over the last three years and a very brief picture of the research program.

In 1954 a reorganization was carried out in the Hydromechanics Laboratory involving the creation of a new division. There are now four divisions, corresponding to the four major categories in the research program:

Ship Powering
Stability and Control
Underwater Acoustics
Seaworthiness and Fluid Dynamics

This arrangement has worked very smoothly and has ensured that the missions and cognizance of each division are clearly defined.

The members of the Laboratory staff have continued to play an important part in many technical fields by membership on various committees of the Bureau of Ships, Bureau of Ordnance, the Office of Naval Research, the Society of Naval Architects and Marine Engineers, the Acoustical Society of America, National Advisory Committee for Aeronautics, and the American and International Towing Tank Conferences.

The International Towing Tank Conference held its 7th meeting in Scandinavia in 1954, which was attended by members of the Laboratory staff, and valuable technical and friendly contacts were made with our colleagues from the many maritime countries interested in our common endeavor.

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