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SOME INTERNATIONAL ASPECTS OF SHIP MODEL RESEARCH

by

Captain E. A. Wright, USN

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Report 1220

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SOME INTERNATIONAL ASPECTS OF SHIP MODEL RESEARCH

THE AUTHOR

is an Engineering Duty Officer who has served 7 years in the United States Fleet, 6 years in naval shipyards, 4 years in warship design, and 6 years in a naval laboratory. He is presently Commanding Officer and Director of the David Taylor Model Basin, and a member of Council of this Society.

EDITOR'S NOTE

Proceeds from this article have been deposited as a "Host Fund" for international visitors to the David Taylor Model Basin.

Ship model research since mid-century has experienced a strong surge throughout the maritime nations of the world. The purpose of this paper is to recognize some of the international growth of possible interest to naval engineers.

The observations are based largely on the International Towing Tank Conference in Madrid, visits to most of the principal European model basins, and the Symposium on Behavior of Ships in a Seaway held at the Netherlands Ship Model Basin, all during September 1957.

I. CONCLUSIONS

WHAT GROWTH is evident in the model basin business abroad and how is the United States doing comparatively? In response to this most frequent question, a few general conclusions are:

a. Widespread construction of new facilities for ship model research is occurring throughout the world. In summary, the number presently under construction or completed since World War II is as follows:

TYPE OF FACILITY	NUMBER
Rotating Arm Basins	7
Seakeeping and Maneuvering Basins	8
Towing Tanks—New	25
Extended	3
Shallow Water Basins and Flow Channels	12
Cavitation Tunnels	15

b. From a purely plant standpoint, foreign model basins momentarily lead the United States in rotating arm basins, seakeeping basins, shallow water basins, and cavitation tunnels, but current building at Carderock will go far to restore our position.

c. General purpose digital computers are an indispensable adjunct to model research in the future, and in the United States relatively great progress has been made in their application.

d. The growth of model basin facilities in association with universities at home and abroad is already proving its wisdom.

e. Ship model research in all countries is now as always wholly dependent on dedicated scientific and engineering personnel with unfettered imagination and applied enthusiasm. Without them, funds and facilities are meaningless.

f. Model basin professionals abroad are highly alert, curious, cosmopolitan, modest, helpful, competent, and progressive. Much is being accomplished by a few.

g. Contributions by the younger set in all delegations to the conferences were particularly impressive.

h. The quality of research in all model basins visited appeared high, but no more so than in the United States.

i. Science has come to naval architecture on a fine broad international front, particularly in stormy fields such as the wavegoing aspects of seakeeping.

j. The concurrent development of theory and experiment has become increasingly widespread to the benefit of generalizing results, understanding the physical phenomena, disciplining the investigators, and promoting international cross-fertilization in the science of ships.

k. The scope of model investigations is being enlarged tremendously from traditional model tests in a straight line to experiments in 2 and 3 dimensions and up to 6 degrees of freedom.

l. The nature of model techniques is likewise expanding rapidly from steady state observations to dynamic and transient conditions.

m. In many countries, inadequate attention is being given to observing flow conditions around models, appendages, and propulsion devices. One look can often reveal more than thousands of routine measurements. A new classic (1) should do much to increase consciousness of the importance of observing and studying flow.

n. The growing need for research in hydroelasticity, as applied to ship design, is beginning to be more widely recognized.

o. Several areas have been researched beyond the point of diminishing returns and could well be dropped from international emphasis.

p. The Union of Soviet Socialist Republics contributed significantly to the conferences and unquestionably is one of the leading countries in hydrodynamic research.

q. Participation in and financial contributions to ship model research abroad by private ship design and shipbuilding interests exceeds greatly support from these sources within the United States. Here the major burden by far is carried by the United States Navy.

r. Because of heavy private support of ship model research abroad, many areas of merchant ship investigation are stimulated much more strongly than in the United States.

s. The United States is still among the leaders in ship model research but will have to hump vigorously to retain this position.

II. INTERNATIONAL AGREEMENTS

The International Towing Tank Conference deals solely with professional tankery; that is, the science of predicting full scale ship behavior from model experiments. The following digest has been prepared to summarize the principal agreements reached and objectives set at the 1957 Conference:

a. All tank establishments will submit detailed descriptions of their present methods for carrying out and analyzing propulsion experiments, for open water propeller experiments, for estimating ship performance, and for comparing trial results with model predictions. From study of the many different procedures, standard methods will be recommended for general international use.

b. In the field of propulsion, international study will be pursued on propeller scale effect including turbulence stimulation, on methods of determining full scale wake factors, on propeller-rudder interaction, on thrust deduction theory and experiment, and on fluctuations of torque and thrust.

c. As the Conference favored a model-ship correlation formula close to the 1947 American Towing Tank Conference (Schoenherr) line above a Reynolds Number of 10^7 but steeper at lower R's, the following was adopted:

$$C_F = \frac{0.075}{\left(\log_{10} \frac{R}{100}\right)^2}$$

to be known as the "ITTC 1957 Model-Ship Correlation Line."

d. In the field of frictional resistance, international study will be pursued on roughness allowances, on effect of form on frictional resistance, on improved techniques in turbulence stimulation, and on tank boundary interference.

e. Propeller work will include systematic investigations in one or two tunnels on the effect of air content on cavitation phenomena, the collection of data to enable comparison between cavitation tunnel tests and full scale results, fundamental work on slotted wall test sections for propeller tests, experiments in different tanks and tunnels on standard propellers, effect of unequal flow distribution, closer coordination between open water and tunnel results, and the relevant properties of water including the effect of nuclei and entrained air.

f. In the seagoing qualities of ships, the proposed studies include the collection of full scale sea and ship performance data to make model tests meaningful, the development of non-dimensional methods of presenting data for head and oblique seas, comparative tests in waves for two geometrically similar models properly scaled, interchange of information on test techniques in waves, and the development of theoretical methods for design and evaluation of experiments.

g. Preparation of standard values for kinematic viscosity of fresh and sea water.

III. THE PEOPLE

The committees appointed by the 1957 International Towing Tank Conference to serve and to implement international agreements until the 1960 conference in Paris are:

Standing Committee

General R. Brard .... France
Captain M. L. Acevedo .... Spain
Professor W. P. A. van Lammeren .... Netherlands
Professor J. K. Lunde .... Norway
Captain H. E. Saunders .... United States
Dr. F. H. Todd .... Great Britain

Scale Effects On Propellers and Self-Propulsion Factors

Dr. Hans Edstrand .... Sweden
Dr. Fritz Gutsche .... Germany
Mr. J. B. Hadler .... United States
Mr. J. Krivtzoff .... U.S.S.R.
Mr. L. P. Maillard .... France
Mr. R. N. Newton .... Great Britain
Professor E. V. Telfer .... Great Britain

Skin Friction and Turbulence Stimulation

Professor C. W. Prohaska .... Denmark
Captain M. L. Acevedo .... Spain
Dr. George Hughes .... Great Britain
Dr. M. Kinoshita .... Japan
Dr. L. Landweber .... United States
Mr. A. J. W. Lap .... Netherlands
Dr. Karl Wieghardt .... Germany

Comparative Cavitation Tests of Propellers

Dr. H. W. Lerbs .... Germany

Professor L. C. Burrill ....Great Britain
Dr. J. D. van Manen ....Netherlands
Mr. L. Mazarredo ....Spain
Ch. Eng. L. Pehrsson ....Sweden
Mr. A. Silverleaf ....Great Britain
Mr. A. J. Tachmindji ....United States

Seagoing Qualities of Ships

Dr. M. St. Denis ....United States
Dr. O. Grim ....Germany
Dr. H. Kato ....Japan
Professor E. V. Lewis ....United States

Mr. E. C. Tupper ....Great Britain
Mr. G. Vossers ....Netherlands
Mr. A. I. Voznessensky .............................U.S.S.R.

Presentation of Resistance and Propulsion Data

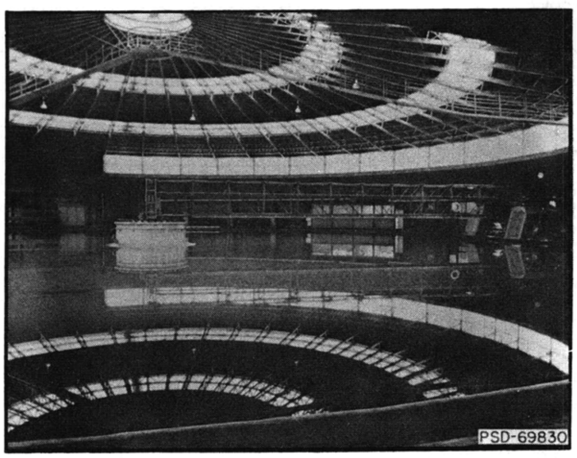
Captain H. E. Saunders ....United States
Dr. E. Castagneto ....Italy
Mr. J. M. Ferguson ....Great Britain
Mr. H. Lackenby ....Great Britain
Mr. S. D. Mathews ....Canada
Dr. H. F. Nordstrom ....Sweden
Professor S. Silovic ....Yugoslavia
Dr. H. Amtsberg ....Germany

IV. PHYSICAL GROWTH

Although laboratory facilities are forever secondary to laboratory people, their growth has interest and significance in that (a) they embody the ideas of their creators, and (b) they represent positive financial commitments of the sponsoring countries to new and extended fields of ship model research. Hence the remainder and majority of this paper are devoted to description of these more factual international aspects.

ROTATING ARM BASINS

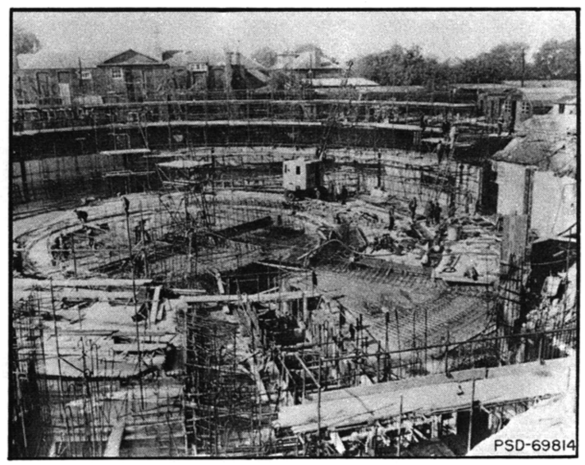
A striking development of the current decade is the increasing ability to predict the course keeping qualities of ships and submarines, and their paths under the influence of control surfaces. The prediction technique depends presently upon the experimental determination of hydrodynamic coefficients for the body and its appendages, the substitution of these coefficients in the differential equations of motion, and the calculation manually or by analog computer of the flight path under different conditions. The rotary coefficients of motion are best obtained by towing the body in a circular path and measuring the forces thereon.



—Courtesy of the Director

Figure 1. The Rotating Arm Facility at the Bassin d'Essais Des Carenes in Paris. The end of the arm to the left in the photograph is pivoted on an island in the center of the basin, and the right end is driven around a peripheral track by the two motors whose hoods can be seen. The overhead catwalks are used for photography.

The first large rotating arm basin designed for the purpose was completed by the French at the Bassin d' Essais des Carenes in Paris in 1945 (2). This circular model basin, 213 feet in diameter and 16 feet deep, has an arm pivoted in the center and rolling at its outer end on a circular track, Figure 1. Two 25 HP motors with Ward-Leonard control drive the outer end of the arm through two rubber-tired wheels at speeds up to 19 knots. The new large towing basin in Paris completing in 1958 connects with the rotating arm basin to permit radio-controlled turning models a long straight accelerating run before the rudder is laid over.



—Courtesy Mr. F. S. Burt

Figure 2. Rotating Beam Basin Under Construction at the Admiralty Research Laboratory. All concrete is heavily reinforced, particularly the footing for the 16-foot diameter concrete base required to support the kingpost within 8 seconds of arc to the vertical.

A rotating arm was installed in the 75-foot square, 4.5-foot deep, maneuvering basin at the Stevens Institute of Technology near the close of World War II, and much pioneering work on the steering and turning of ship models has been done in this facility.

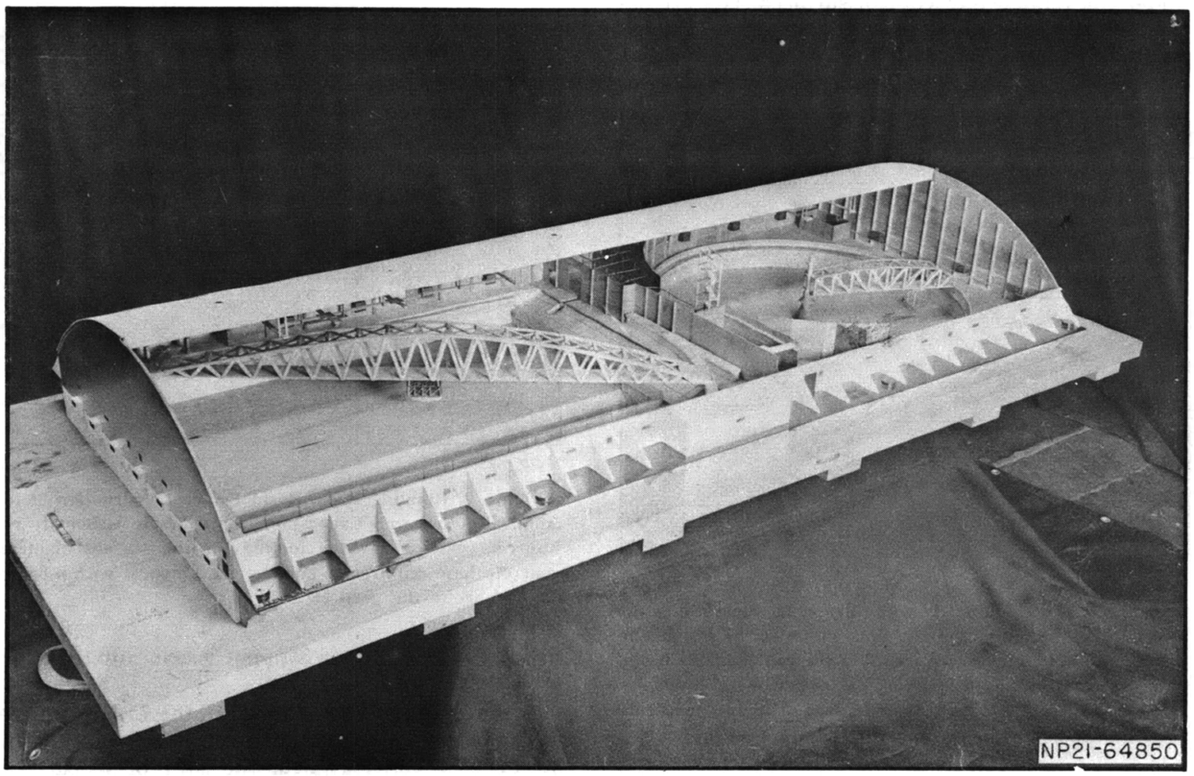
At the Admiralty Research Laboratory, Teddington, England, a rotating-beam channel (3) has recently been completed and embodies spectacular engineering performance. The annular channel, shown under construction in Figure 2, has an outside diameter of 136 feet, a depth of 15 feet, and is 34 feet wide. Spoilers and beaches inhibit currents, wave reflections, and hydraulic resonance. The rotating beam, Figure 3, is supported and driven at the center only. The beam moves at a maximum peripheral speed of 90 knots at the 50-foot radius, while supporting a model weighing 3,000 pounds and creating a drag force of 4,000 pounds applied 5 feet below the water surface. Centrifugal acceleration is 14g. Underwater, large picture windows, which if broken will be closed automatically by steel shutters, provide comfortable observation stations.

At the Admiralty Experiment Works, Haslar, England, which serves the same ship design needs for the British Navy as the David Taylor Model Basin does for the U. S. Navy, extensive construction is underway for new ship model research. A rotary arm facility will form a part of a large maneuvering and seakeeping basin (4) now building.

The maneuvering basin at the Hamburgische Schiffbau Versuchsanstalt is 82 feet in diameter and tangent to the main towing tank at one end. This arrangement provides a straight accelerating run under the towing carriage before the model goes into a turn, like the "J" basin at Carderock. The Hamburg tank is fitted with a rotating arm.

—Courtesy Mr. F. S. Burt

Figure 3. Rotating Beam Basin Completed at the Admiralty Research Laboratory. Through the highly-filtered water can be seen the swirl plates radially in the basin floor and the viewing ports in the island. The 122-foot symmetrical beam weighing 60 tons rotates at speeds up to 1 revolution every 2 seconds.



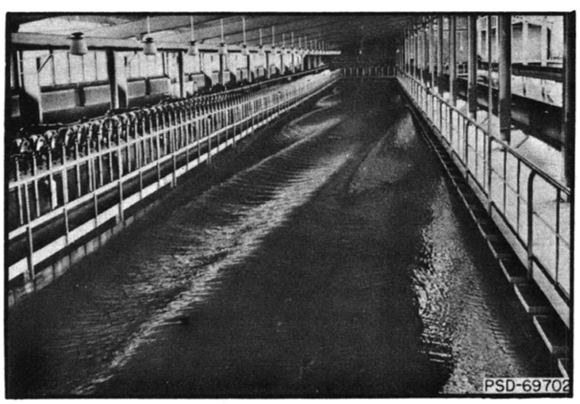
—Official U. S. Navy

Figure 4. Arrangement Model of Rotating Arm and Maneuvering Basins Under Construction at Carderock. Except for housing under the same roof, with an open span of 274 feet by 692 feet, the basins are physically and functionally separate with the maneuvering basin to the left in the photograph and the rotating arm basin to the right.

The rotating arm facility under construction at the David Taylor Model Basin will be housed with, but entirely separate from, the new maneuvering basin, Figure 4. To permit using the same standard 20-foot model throughout all the various tests at Carderock, the circular basin will be 260 feet in diameter with a water depth of 20 feet (5). The 38,000-pound, tubular aluminum, rotating arm will be driven by two 250 HP motors through 30-inch steel wheels rolling on a peripheral steel track. The arm is designed to accelerate from rest to 30 knots at the 120-foot radius in ½ revolution to permit readings on surface ship models before they overtake their surface wave system. Maximum arm speed at the 120-foot radius will be 50 knots. A 20-foot submarine weighing 2600 pounds held by struts 10 feet below the water surface can attain a 12 knot arm speed within one-half a turn for any radius between 48 and 120 feet. On the underside of the rotating arm, there will be a small carriage which can be remotely controlled to position the model in radius, roll, pitch and yaw.

SEAKEEPING AND MANEUVERING BASINS

Worldwide scientific attention is being brought to focus on the seakeeping qualities of surface ships. At the Symposium in the Netherlands, 45 important technical papers covering every aspect of wavegoing were presented; among the authors were representatives of the National Institute of Oceanography in Great Britain, University of Tokyo, A. N. Kryloff Shipbuilding Research Institute of the U.S.S.R., Stevens Institute of Technology, University of California, Hamburgische Schiffbau Versuchsanstalt, Transportation Technical Research Institute of Japan, Massachusetts Institute of Technology, New York University, Technical University Berlin-Charlottenburg, Iowa Institute of Hydraulic Research, King's College, Netherlands Meteorological Institute, Royal Netherlands Navy, University of Trieste, National Physical Laboratory, Delft Shipbuilding Laboratory, National Research Council of Canada, Netherlands Ship Model Basin, Stanford University, Leningrad Shipbuilding Institute, and David Taylor Model Basin (6).



—Courtesy Professor W. P. A. van Lammeren

Figure 5. First Seakeeping Basin, created by the Netherlands Ship Model Basin. The angles and complexity of the waves are varied by snake-type generators along the left side in the photograph and at the far end. The towing carriage runs in a fixed direction on the rails which can be seen through the right hand row of columns.

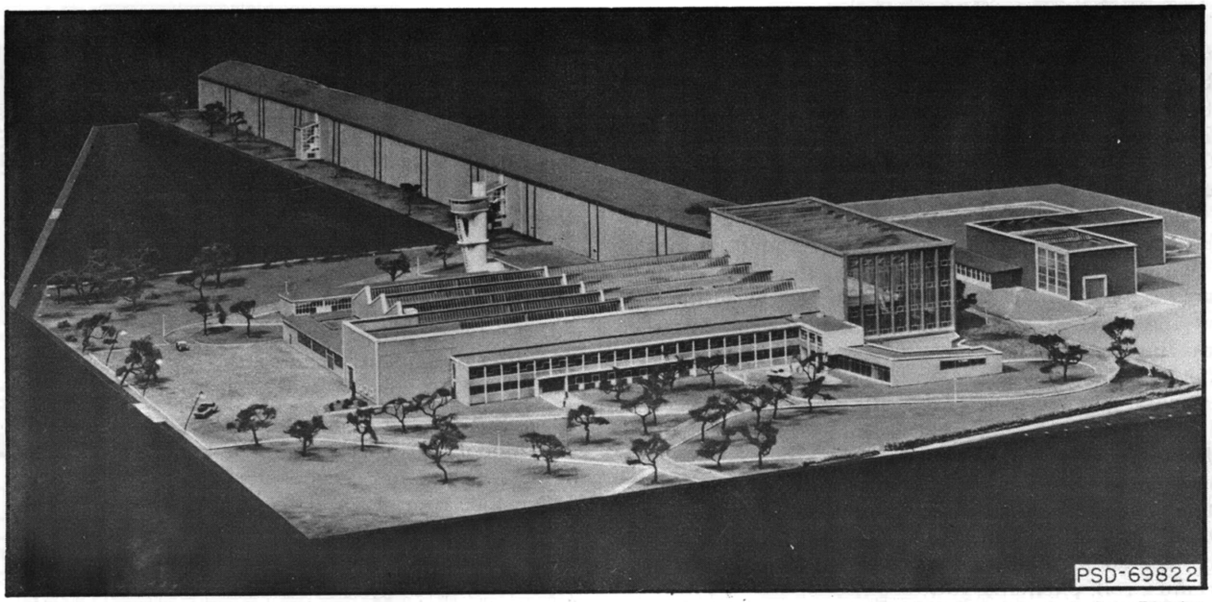
Ship model research in seakeeping calls for controlled tests not only in regular head and following waves as has been the practice, but also in irregular and short-crested waves at various angles of encounter. Consequently a new type of model basin is needed.

The Seakeeping Laboratory of the Netherlands Ship Model Basin (7), completed in May 1956, is the first facility in operation for ship model tests in a wide spectrum of simulated sea conditions. In the snake type wave generators, elements 2 feet wide can be phased to send out wave trains in a wide choice of directions and crest shapes, Figure 5. Then, with such wavemakers on two adjacent sides of the basin, patterns of irregular short-crested waves can be obtained. Consequently, the towing carriage need run only in a fixed direction. The 9-ton carriage is driven up to 10 knots by 3.7 HP motors to each of four 39-inch wheels on rails supported by two rows of pillars for the length of the 328-foot basin. The basin is 80 feet wide and 8 feet deep. The models, 10 to 13 feet in length, are self-propelled and fitted with automatic steering gear.

The Stevens Institute of Technology has put into operation a plunger type of wavemaker along one 75-foot side of their square maneuvering basin (8). Long-crested regular and irregular waves will be generated primarily, with provision for short-crested seas by temporary local extensions of the wavemaker face. A bridge, which can be positioned across the basin at various angles to the wave system, will carry on the underside a light towing carriage. Models approximately 4 feet long are contemplated.

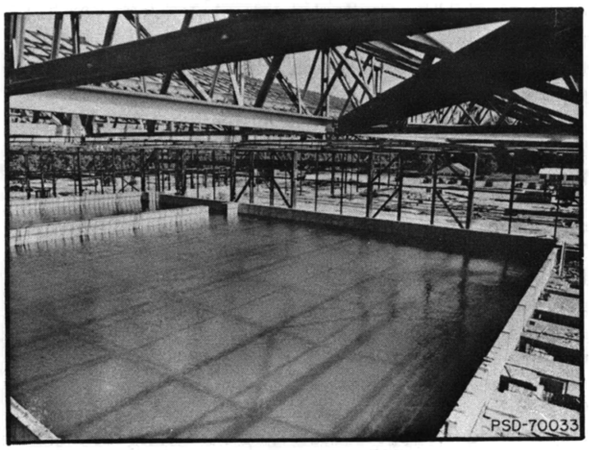
At Feltham 5 miles from Teddington, the National Physical Laboratory is building a completely new Ship Hydrodynamics Laboratory, Figure 6, with all of the balanced components and facilities for the operation and support of modern ship model research (9). Included in the construction is a maneuvering and seakeeping basin, 100 feet square by 8 feet deep, Figure 7. Along one wall is being provided a continuous plunger type wavemaker, with a deep hollow-faced wedge, to generate waves up to 15 feet long and 9 inches high. Later an articulated plunger-type wavemaker will be added along an adjacent wall to superimpose waves at different angles on the main pattern. Free-running, radio-controlled models in the order of 10 feet long are contemplated for both maneuvering and wavegoing tests.

Announcement was made at the 1957 internation-



—Courtesy Superintendent, Ship Division

Figure 6. Model of Main Building Group of the New NPL Ship Laboratory at Feltham, England. The maneuvering basin-shop group is to the left, the new deep water basin in the center, and the cavitation tunnel building to the right.



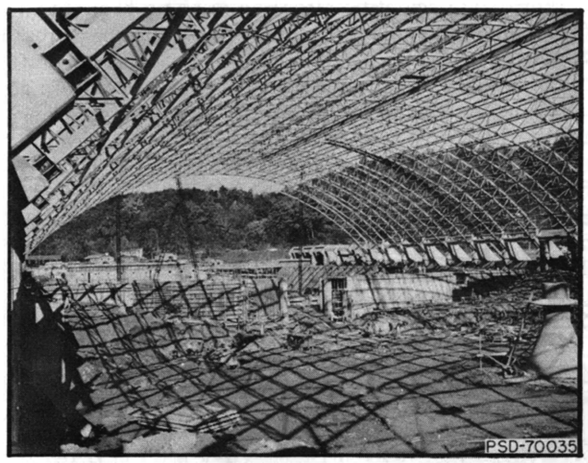
—Courtesy Superintendent, Ship Division

Figure 7. Maneuvering Basin Under Construction at Feltham. The wax model storage and transfer tank in the background will connect the model shops and the main towing basin.

al conferences that the Admiralty Experiment Works at Haslar has under construction a large seakeeping and maneuvering basin. Principal dimensions will be a length of 400 feet, a width of 200 feet, and a water depth of 18 feet. Plunger type wavemakers will be installed at one end and along one-half of the long side of the basin.

In Canada, the National Research Council at its model basin at Ottawa is constructing a large maneuvering basin 400 feet long by 200 feet wide by 10 feet deep. Wavemakers may be added in the future.

At the Technical Research Institute in Tokyo, self-propelled models 26 to 28 feet long in which 1 or 2 men ride are tested for maneuvering qualities. The basin is shaped like a right-angled triangle, over 600 feet on one leg and 440 feet on the other leg, with a depth of 20 feet. A 60-foot tower in the center is used to photograph the model paths.



—Official U. S. Navy

Figure 8. Construction of DTMB Seakeeping and Maneuvering Basin. The seakeeping basin will be at the far end; holes for the pneumatic wavemaker ducts can be seen near the tops of the basin walls. The rotating arm basin will be at the near end; the center support can be seen to the right in the photograph.

The U.S.S.R. delegation to the International Towing Tank Conference announced the construction of a tremendous new open maneuvering and seakeeping basin (10). This facility will have a width of 230 feet, a length of 558 feet, and a depth of 18 feet. Plunger type wavemakers for this basin are under construction and nearing completion.

At the David Taylor Model Basin, as at the Admiralty Experiment Works, the physical dimensions of the maneuvering and seakeeping basin were selected so that models of the standard length could be tested. The rectangular basin therefore has a length of 360 feet, width of 240 feet, and depth of 20 feet over most of the floor area, Figure 8. Parallel to a long wall, a 50-foot wide trench is being provided to have a water depth of 35 feet for testing free-running, submarine models and for observing them through windows in the wall. The wavemakers will be pneumatic, run the length of two adjacent walls, generate waves up to 40 feet long and 2 feet high, and absorb about 2500 HP at maximum load. Considerable flexibility is being built into operation and control of the wavemakers to permit creation of a wide range of controlled sea conditions. The highly effective grid type beach design is the result of exhaustive experiments at the St. Anthony Falls Hydraulic Laboratory. Spanning the length of the basin, and movable between runs to angles from 0 to 45 degrees to the basin axes, is a 376-foot bridge weighing about 230 tons which carries an aluminum towing carriage on its underside. The carriage will have a maximum speed of 15 knots, will accelerate up to 0.4g by the tractive effort of rubber tires driven by two 30 HP motors, and carry operating personnel, controls, and instrumentation for constrained and free-running models.

In addition to specialized seakeeping model basins, many laboratories are providing or improving wave making and absorbing equipment in their main basins. These will be described under the section on Towing Tanks.

The validity of seakeeping predictions from ship model tests must first be established by correlation with precise observations of full scale ship behavior under known sea conditions. In preparation for such correlations, a number of seakeeping trials are in various stages of completion.

The Royal Netherlands Navy and the David Taylor Model Basin, assisted by the Institute of Applied Physical Research in Delft and the University of Ghent, have conducted extensive seaworthiness trials on the destroyers HNMS *Friesland, Zeeland,* and *Everstsen* (6). Simultaneous measurements were made of roll and pitch angles; transverse, longitudinal and vertical accelerations, hull stresses in deck and keel, and bottom pressure at 8 stations along the length.

The U. S. Maritime Commission, Bureau of Ships, and David Taylor Model Basin are conducting seakeeping trials on two 6,000 HP Liberty ships, one of which has been lengthened 25 feet and the forebody considerably fined. Not only are the ship motions and accelerations being measured concurrently and comprehensively, but also the sea state with equipment developed by the British Institute of Oceanography at Wormley. These shipborne meters correct static wave pressure readings for roll of ship and for heave by double integration of accelerometer signals.

The Swedish Shipbuilding Research Association and the David Taylor Model Basin are collaborating on full scale strain and motion observations in the high-speed cargo ship MS *Canada.* Several round trips have been made from Sweden to Vancouver, and joint analysis of the observations is being undertaken. Shipbuilding Research Associations in Great Britain and a number of other countries are engaged in explorations of this kind.

The U.S.S.R. has developed considerable instrumentation for full scale trials, including gyro-recorders for ship motions, pressure gages for hydrodynamic loadings, and strain gages for measurement of hull stresses (10). During full scale trials under a variety of sea conditions, waves are measured by wave pole, by buoy and by stereophotography. The buoys are equipped with radio telemetering apparatus for transmitting information to shipboard on wave heights and periods.

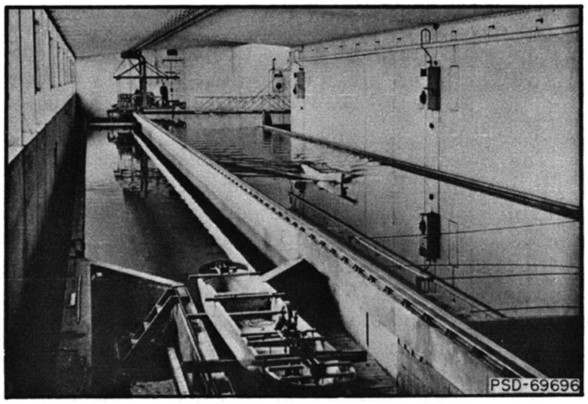
The subject of Dynamic Forces and Moments in a Seaway was included in the formal agenda of the International Towing Tank Conference for the first time in 1957. This step recognizes that study of elastic responses in a ship, such as strains, accelerations, pressures, and vibrations, depends basically on increasing knowledge of the exciting hydrodynamic forces. Conversely, these forces can be markedly effected by the elastic character of the interface.

Under the sponsorship of the Bureau of Ships and technical cognizance of the David Taylor Model Basin, instrumentation has been devised and tests run by the Stevens Institute of Technology on a destroyer model in waves. Not only the bending moment but also the shear amidships was measured, and it has been possible to reproduce in the model the 2-noded natural hull frequency corresponding to this vertical vibration characteristic in the ship (10). This pioneering technique was initially triggered by the Society of Naval Architects and Marine Engineers.

Loading studies on ship models in waves, undertaken for the first time in Japan, are now also done at the Massachusetts Institute of Technology, Vickers-Armstrong in St. Albans, and others. Delft Technical University uses a plastic model, rather than a split model, and finds it convenient for observing hull strains in any direction. The Kryloff Shipbuilding Research Institute at Leningrad studies forces on a ship model in a seaway by measuring pressures on the hull, by strains produced in a split model, and by measuring accelerations.

TOWING TANKS

The Director of the Canal de Experiencias Hidrodinamicas at El Pardo was Chairman of the Stand-



—Courtesy Dr. H. W. Lerbs

Figure 9. Hamburg Model Basin Complex of Facilities for Medium Sized Models. From the left can be seen the combined shallow water basin and flow channel, the monorail towing carriage which serves the basins on each side, the maneuvering basin with rotating arm projecting, and the main basin.

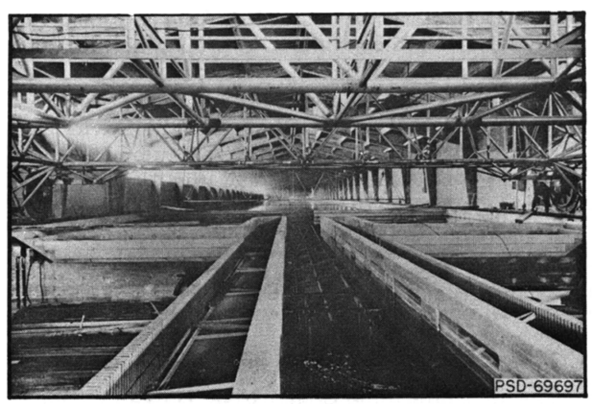
ing Committee of the International Towing Tank Conference and host to the Eighth Meeting held in Madrid. Through his most thorough and hospitable arrangements, 96 model basin directors and delegates from 21 nations met in valuable technical sessions covering many aspects of tankery. The reports, discussions, decisions and recommendations are being distributed by the Spanish Organizing Committee. During the Conference, opportunity was provided to visit and to see in operation the complete facilities at El Pardo. The main towing tank was lengthened 360 feet in 1946 to a new length of 1050 feet. The original cross-section, 41 feet wide by 21 feet deep, was retained throughout.

One of the most remarkable laboratory advances of this decade is occurring at the Hamburgische Schiffbau Versuchsanstalt in Western Germany. With the pre-War basins in ruins, a completely fresh start has been made in another section of the city. Since opening in 1950, over 820 ship models and 560 propeller models have been made and tested.

Initially at Hamburg, a compact complex of flexible medium-sized facilities has been built, Figure 9. The main towing tank is 260 feet long, 16 feet wide and 10 feet deep for testing models about 15 feet long. When the portable plunger type wave generator is installed in the fitting dock end of the main basin, the water level is dropped below the fixed side beaches and wave quashing screens are lowered into the water between runs to reduce the waiting interval. The maneuvering basin is at the opposite end of the main tank. Unique among model basins, as far as known, is the monorail design of towing carriage at Hamburg. On the upper rail, supported by the reinforced concrete roof, run only carriage guide wheels. The lower rail carries guiding, weight, and tractive forces. Generators on the carriage supply the two main driving motors as well as the model under test. Maximum carriage speed is 7 knots; an independent wire towing arrangement is also provided over this basin for tests up to 12 knots. The monorail carriage travels between the shallow water basin and the main basin, overhanging both. Hence unobstructed views and photographs of the models under test can be obtained opposite the towing carriage.

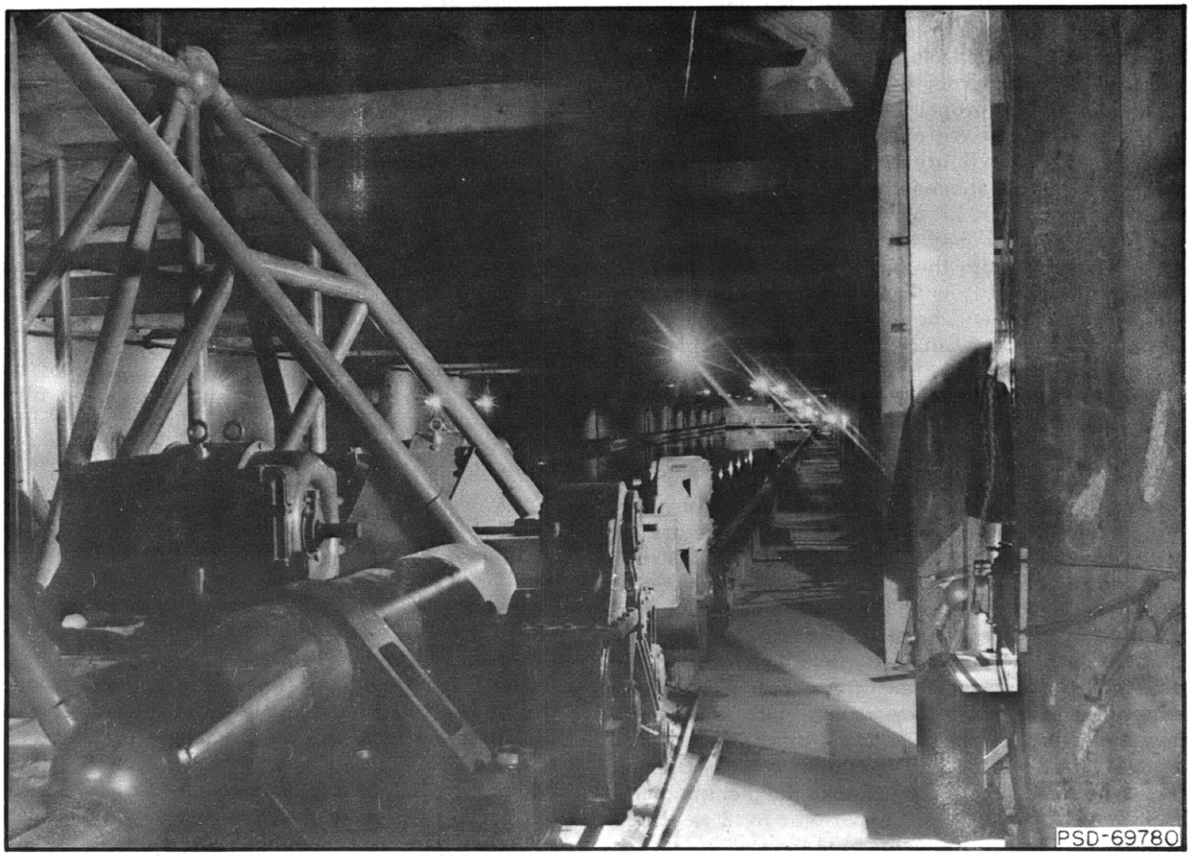
New large facilities are under construction at Hamburg. The model basin, Figure 10, was filled for the first time in March 1956, and alignment of the rails is well advanced. The basin cross-section of 59 feet by 20 feet will provide an exceptionally large hydraulic radius. The present length of 656 feet is extensible to 1480 feet if required in the future. Rail laying is well advanced. The new towing carriage will be a massive precision instrument of highly original design. Its anticipated structural weight is 15 tons, total weight 26 tons. Four large wheels over 4 feet in diameter, each motor driven through gears, will propel the carriage at speeds up to 20 knots. Track brakes will grip the rail head for emergency stopping at any point, as at Carderock. Within the large rectangular bay of the main towing carriage, a secondary carriage will run athwartships, making possible in effect concurrent motion in both the X and Y directions. Thus it will be possible to execute zigzag maneuvers, and to run a model with waves on the bow and quarter as well as dead ahead and astern. The underside of the carriage is well elevated above the water surface. A plunger type wavemaker is planned. These fine new facilities at the Hamburgische Schiffbau Versuchsantalt are expected to commence operation by late Spring 1958.

At the Bassin d'Essais des Carenes in Paris (11), an equally impressive new model basin and towing carriage are in a comparable stage of construction, Figure 11. This large basin has a cross-section 40 feet wide by 15 feet deep, and a length on the water



—Courtesy Dr. H. W. Lerbs

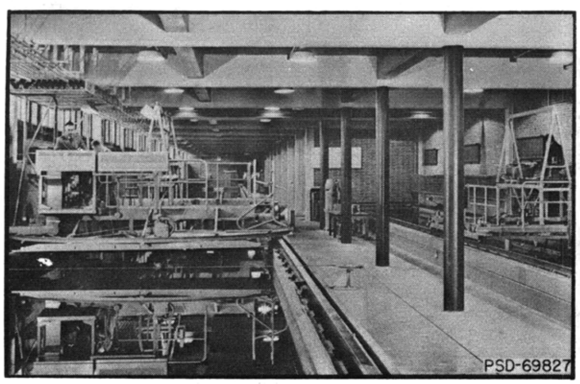
Figure 10. Widest Model Basin Spanned by a Towing Carriage, nearing Completion at the Hamburgische Schiffbau Versuchsanstalt. Above the fitting basin in the foreground can be seen the truss members of the new towing carriage and, at the extreme left and right, the large carriage drive wheels.



—Courtesy of the Director

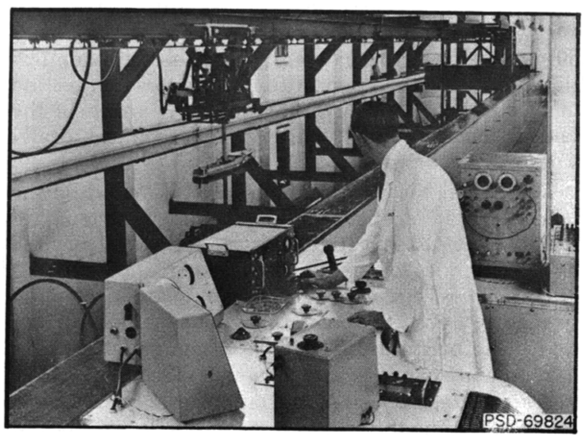
Figure 11. New Deep Water Basin and Carriage at the Paris Model Basin. Two of the four carriage driving units and a set of guide wheels can be seen. The stiff tubular construction is particularly well designed.

of 722 feet. It connects through double watertight gates to the circular maneuvering basin so that approach runs can be obtained. The watertight gates also provide a drydock without disturbing operations in either basin. The tubular carriage structure, with as many as 10 members joined at a single sphere, will be one of the sturdiest and stiffest in existence, attributes which are extremely important



Courtesy Ir. Jelle Gerritsma

Figure 12. New Facilities of the University of Technology at Delft. To the left is the main tank and towing carriage; to the right is the combined shallow water basin and flow channel, also equipped with a carriage.



Courtesy Mr. W. A. Crago

Figure 13. New Tank and Monorail Carriage Opened at Saunders-Roe in 1956. All carriage operations are controlled from and readings are transmitted to the console in the foreground.

in these days of diverse unforseeable demands for surface and subsurface experiments. The carriage is trapezoidal in overall plan form, and all driving and guiding are done from the same heavy rail. Four drive motors will propel the carriage at a maximum speed of 20 knots. An open dynamometer bay will provide great flexibility and economy in carriage time by rigging instrumentation for a particular test on shore and then lifting the entire assembly into the dynamometer bay. Windows for underwater viewing are set into the basin walls. It is expected that this fine facility will be in operation before the end of 1958, and will be a highlight of the next International Towing Tank Conference being planned for Paris in 1960.

The fruitfulness of having a model basin as a part of a school of naval architecture has been widely recognized and utilized. In Holland, the teamwork is carried to 3-way collaboration between the Netherlands Ship Model Basin, the University of Technology at Delft, and the Shipbuilding Laboratory of that University. Excellent new facilities for instruction and research in naval architecture have recently been completed at Delft (12). The towing tank has a length of 316 feet, and a rectangular cross-section 14 by 8 feet. A pneumatic type of wave generator produces not only regular waves, but also can be externally programmed on a plug board, like some new types of console calculating machines, to produce a wide variety of irregular waves. Blower power up to 25 HP supplying air to the plenum dome will generate waves with periods to 2 seconds, lengths to 20 feet, and heights to 11 inches.

Delft's towing carriage, weighing 5 tons, is propelled at speeds up to 15 knots by four 5 KW motors driving each of four 23-inch wheels, Figure 12. Complete instrumentation for resistance, propulsion, open-water propeller, and wavegoing tests are carried, together with a wire-resistance type of wave height meter. When self-propelling in waves, a small light secondary carriage provides full freedom in surge, pitch and heave, and tests of a DTMB Series 60 model in a head sea were witnessed with admiration. On the return run of the carriage when testing in waves, a wide board extending the width of the tank is lowered onto the water surface, and literally irons out the residual waves.

The model basins at Saunders-Roe Limited on the Isle of Wight are engaged in a wide spectrum of scaled dynamic investigations, all the way from the hydrodynamics of ski-supported seaplanes and the ditching of every class of aircraft to tests of minesweepers, hydrofoil boats, and all types of surface craft. The original 618-foot basin completed in 1946 has a towing carriage that attains a speed of 35 knots. Forced rolling and fin stabilization tests were underway at the time of visit. The second tank was opened in June 1956 (13). Here, from the monorail carriage, 14 instantaneous observations can be transmitted through a looped multicore cable to the control console, Figure 13. A 10 HP winch drives the light carriage at speeds up to 30 knots. Tank dimensions are length 250 feet, width 12 feet, and depth 6 feet; the cross-section is rectangular. The new tank has been fitted with a wavemaker of the plunger type and tests of a high speed surface craft in waves were observed.

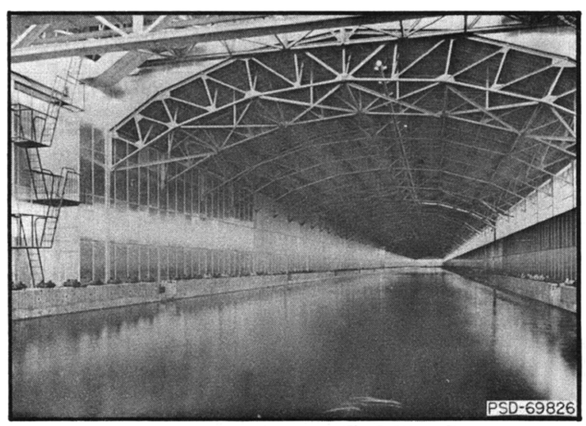
The Stevens Institute of Technology has been conducting sea-keeping experiments in their original towing tank, now fitted with a programmed generator for irregular waves.

In Berlin, a pneumatic type of wavemaker, that generates from the action of air suction as well as air pressure on the water surface in the dome, has now been put into operation.

At Feltham, the large new towing tank of the National Physical Laboratory had just been filled at the time of visit and track laying of all-welded rails was beginning. The generous cross-section of the tank, 48 feet by 25 feet, was determined by the desire to test larger self-propelled models, of the order of 24 feet long (9). Shop machinery is planned to process wax or wood models up to 40 feet in length. The towing carriage is designed for a 7-second steady run at 30 knots on a tank length of 1300 feet. The main tank, Figure 14, is almost entirely above ground level.

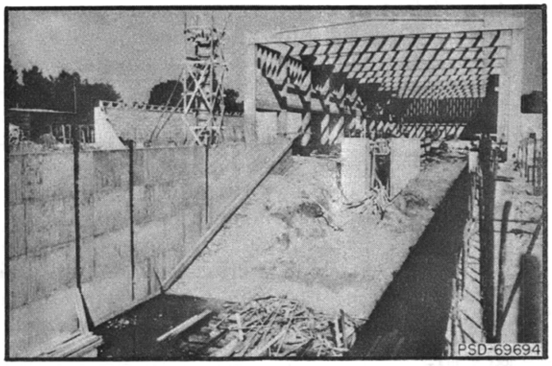
The Danish model basin is now under construction at Hjortekaer just north of Copenhagen, Figure 15. The main tank will have a length of 788 feet, a width of 39 feet and a depth of 18 feet. It will be filled in the late Spring of 1958 and track laying will begin. The towing carriage is already under construction. The new plant will also include an aerodynamic laboratory.

In North America, the National Research Council of Canada completed a new model basin in its Division of Mechanical Engineering at Ottawa in 1951. The tank is 450 feet by 25 feet by 10 feet (14). A 30 HP drive motor propels the towing carriage at speeds



—Courtesy Superintendent, Ship Division

Figure 14. Deepest Model Basin Spanned By a Towing Carriage, part of the New Feltham Complex of the National Physical Laboratory. Roof structure and side paneling are all of aluminum, giving a striking appearance to the interior of the long basin building.

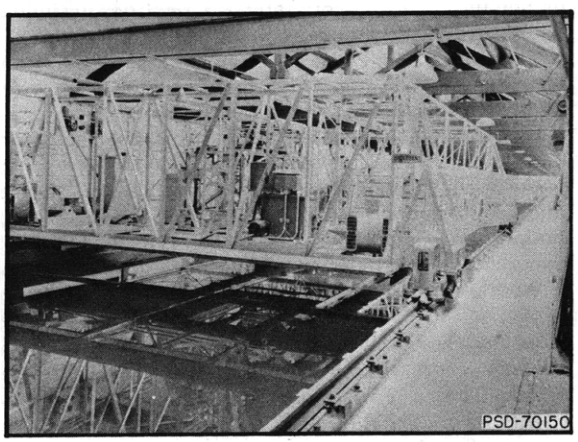


—Courtesy Professor C. W. Prohaska

Figure 15. Fine New Facilities for Denmark are under Construction. View of eastern end and part of workshops.

up to 12 knots. MIT's 108-foot tank was put into operation in February 1951 (15). A programmed wave generator has now been added. The Robinson Model Basin at the Webb Institute of Naval Architecture was also completed in 1951. The U. S. Naval Academy at Annapolis now has a towing tank for the instruction of midshipmen (16). The tank is 52 feet by 6 feet by 4 feet, and is fitted with a gravity dynamometer and electronic speed calculator. The new tank of the University of California at Richmond became operational in the Fall of 1955. It is 200 by 8 by 6 feet, has both towing carriage and wave generator, and is being used for a variety of research including ship motions (17). Convair Division of General Dynamics at San Diego has a new 300-foot tank (18) as a part of its growing hydrodynamics laboratory. The planned facilities contemplate a second 300-foot tank in line with the first, and with a 100-foot square turning basin between them. The light monorail carriage can be operated up to 60 knots.

In 1951, an extension of 302 feet was made to the 35 by 18 foot main tank at the Netherlands Ship Model Basin, making the present length on the water 827 feet.



—Courtesy of the Superintendent

Figure 16. Completely Modernized Original Tank at the Admiralty Experiment Works. The new carriage is driven by a synchronous motor at each corner.

The original tank at the Admiralty Experiment Works was lengthened in 1957, together with new shops and drawing rooms in the extension (4). The tank is now 540 feet long by 20 feet wide by 9 feet deep. The wooden box girder towing carriage designed and built by William Froude has now been replaced by a completely new towing carriage, Figure 16. It is remarkable that the original Froude paddle type wavemaker was in such good condition that it was largely relocated at the extended end of the basin; waves up to 1 foot high and 20 feet long can be generated.

The new tank under construction in India is understood to be about 500 feet long, with a 12 by 7 foot cross-section and with a carriage speed up to 12 knots.

The Genoa tank, completed in 1947, is 158 feet long, 9 feet wide and 5 feet deep.

In late 1953, excavation started for the Istanbul Model Experimental Tank as a component of the Turkish Shipbuilding and Research Institute founded the same year (19). The towing tank is 245 feet long with a cross-section about 20 feet wide and 12 feet deep. The carriage, weighing approximately 9 tons, will be propelled up to 14 knots.

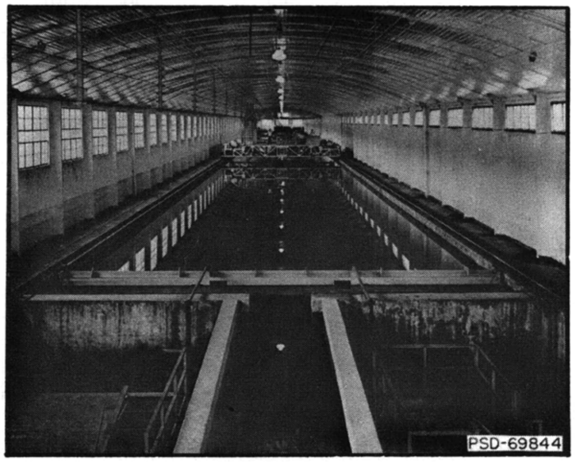
The Kryloff Shipbuilding Research Institute in Leningrad is unquestionably doing important scientific work in ship model research, as well as accomplishing an imposing amount of resistance and propulsion testing, in support of an extensive ship design and building program (20). The main tank there is so long, in the order of 2130 feet, that a number of readings at different speed settings can be obtained in one trip down the basin; this tank is 50 feet wide and 23 feet deep. The second tank is 490 feet by 20 feet by 13 feet. Both towing tanks at Leningrad have now been equipped with eccentric rotating drum type wavemakers. The tanks are apparently working a full 16 hours daily, and the large professional staff of perhaps 150 to 200 is very active. Russian representatives of the Kryloff Institute and of the Academy of Sciences in Moscow made significant technical contributions to both the Wageningen and Madrid conferences, and will in the future be represented on the technical committees of the International Towing Tank Conference.

In Brazil, the Naval Section of the Technical Research Institute has recently completed at Sao Paulo a ship model testing tank 197 feet long, 12 feet wide and 7.5 feet deep (21). The towing carriage for this new facility corresponds to those of larger basins, for it is designed to undertake propeller and self-propulsion as well as resistance tests, and to carry model testing personnel and the carriage operator. The rectangular 20 by 13 foot carriage weighing about 4 tons will have a speed range up to 10 knots.

The Mitsubishi model basins at Nagasaki, destroyed by the bomb, have now been completely rebuilt and in full operation since August 1953 (22). Principal features are:

	Medium Tank	Large Tank
Length, feet	394	542
Width, feet	20	41
Depth, feet	12	21
Carriage drive, HP	12	100
Speed, max., knots	12	17
Models, max., feet	20	26

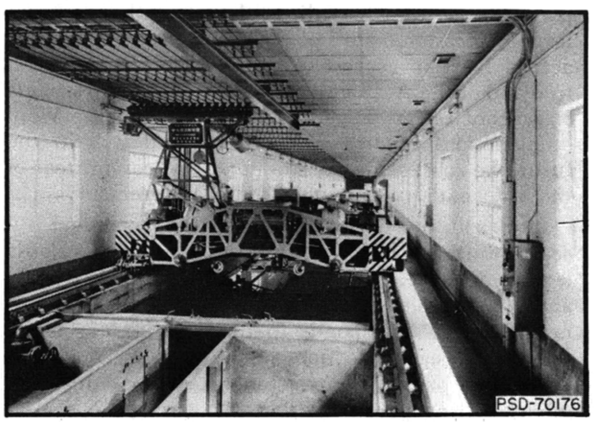
The two tanks are in tandem so that the large towing carriage can run the length of both tanks. A 30 HP wavemaker serves the large tank, Figure 17.



—Courtesy Hideo Fujita

Figure 17. The Mitsubishi Nagasaki Experimental Tank. Carriage and housing have been completely rebuilt; the flap of the new wavemaker can be seen in the foreground.

Extensive construction of new facilities is currently underway at the Meguro Model Basin of the Technical Research Institute in Tokyo. Completed in 1956, the small basin is 336 feet long by 11 feet wide and 7 feet deep, with a towing carriage driven up to 14 knots by four 7.5 HP motors, Figure 18. A pneumatic wavemaker for this basin was completed



—Courtesy M. Kanno

Figure 18. Small Tank at the Meguro Model Basin. Auxiliary pneumatic tires are used on concrete rails at both tank ends for high acceleration and deceleration.

in 1957. The large basin, 836 feet long with a cross-section 41 feet by 24 feet, is in the rail laying stage, Figure 19. The steel-tube all-welded towing carriage will be 52 feet long, will weigh 30 tons, and will be driven up to 32 knots by four 35 HP drive motors. A flap-type wavemaker, driven by a 100 HP motor and capable of generating waves over 3 feet high, has been installed in the large basin. Likewise building is a third basin 1140 feet long, 20 feet wide and 10 feet deep for still higher speed experiments.

At Kings' College in the University of Durham, a tank 130 feet long with a cross-section 12 by 5 feet was completed in July 1952 (23) for research and instruction in the Department of Naval Architecture, the first arrangement of this kind in England.

Since November 1951, full operations have been resumed in the Schiffbautechnishe Versuchsanstalt in Vienna, Figure 20. The basin is 590 feet by 33 feet by 16 feet, and the maximum carriage speed is 15 knots. This basin was heavily damaged in World War II.

At the Shipbuilding Research Institute in Zagreb, Yugoslavia, extensive construction is underway. Of the 4 new model basins now building, one will be a deep water basin about 905 feet long, 40 feet wide by 21 feet deep, and another a high speed basin almost 1000 feet long with a cross-section 16 by 10 feet and a carriage speed of 40 knots. Details will be announced at the time of opening, probably next year.

Considerable progress is being made in the development of techniques and instrumentation for resistance and propulsion experiments on submerged bodies in towing tanks, such as at the National Institute for the Study and Testing of Naval Architecture in Rome, Figure 21.

SHALLOW WATER BASINS AND FLOW CHANNELS

Channels at model basin establishments appear to be of three general varieties: (a) Shallow water basins in which the water is at rest and the towing carriage moves, (b) channels using either a carriage or flowing water or both, and (c) facilities designed for observing a stationary model in moving water.

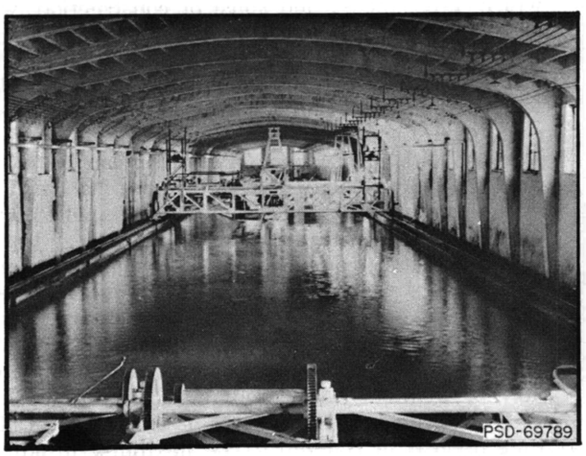
The Paris Model Basin completed and put into operation in 1956 a separate shallow water basin with depth from 0 to 6.5 feet, utilizing the basin floor as was done at Carderock. This basin is 508 feet long and 30 feet wide, and will be used for maneuvering experiments in shallow water as well as resistance and propulsion, Figure 22. The towing carriage has a maximum speed of 10 knots. A gate type wavemaker was ready for installation when this tank was visited.

Another new addition to the Netherlands Ship Model Basin will be facilities for inland waterway tests and research (24). Construction is now well underway on this basin, Figure 23, which will be 712 feet long, 52 feet wide and 4 feet deep. Experimental work in this basin is already programmed over its first 5 years.

At Duisburg-Neudorf in Western Germany, special facilities were built about 1954 for the study of

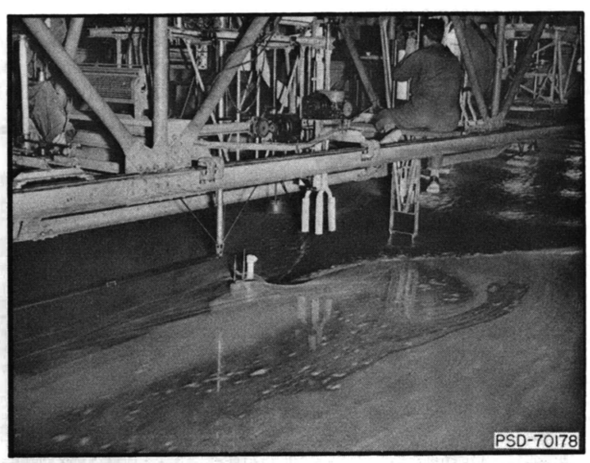
—Courtesy M. Kanno

Figure 19. New Large Meguro Tank of the Technical Research Institute, Japan. Completion of the rails, carriage and dynamometer is anticipated in 1958.



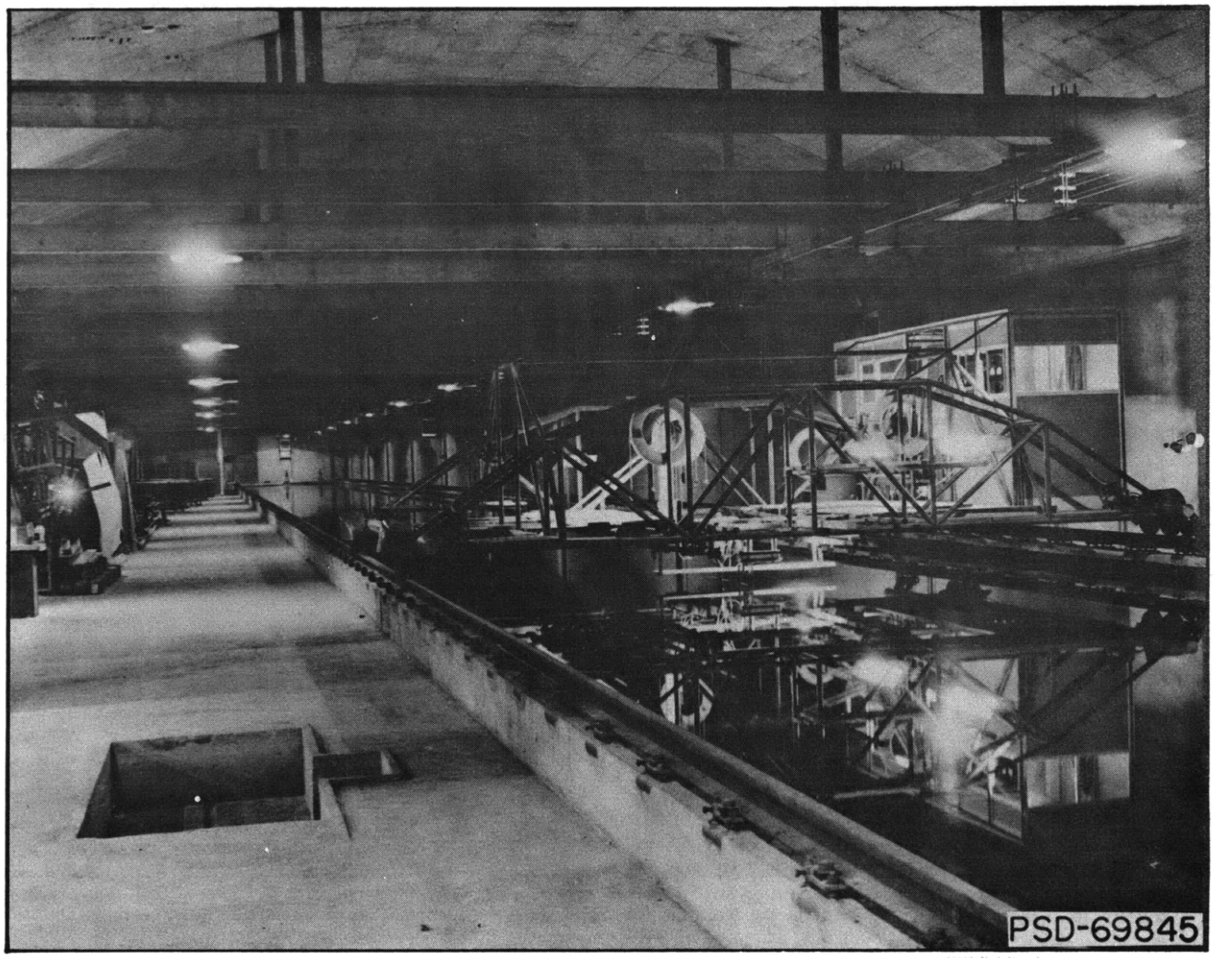
—Courtesy Dr. Leopold Kretschmer

Figure 20. War Damage Now Repaired at Original Gebers Tank In Vienna.



—Courtesy U. Pugliese

Figure 21. Towing Tests of a Submarine Model at the Rome Model Basin. Dynamometers have been built for self-propulsion experiments on submerged bodies.



—Courtesy of the Director

Figure 22. New Shallow Water Basin at Paris. A large towing carriage, complete with instrument room, is provided entirely for shallow water.

craft for inland waterways. The shallow water tank there is 130 feet long and 10 feet wide with a towing carriage. In addition, there is a large shallow tank

—Courtesy Dr. W. P. A. van Lammeren

Figure 23. The Netherlands Builds a Shallow Water Model Basin. A new maneuvering pond is in the background.

which, after the second stage of construction, will be 360 feet long.

The Delft flow channel (12) has a length of 147 feet, a width of 9 feet, and a depth over an accurately-levelled bottom variable from 0 to 1.6 feet. A carriage over the channel will tow at speeds up to 5 knots in either direction. The water can be made to flow up to a velocity of 2 knots in the channel. The water circulates in a flat vertical loop, impelled by a 4-bladed 30 HP propeller.

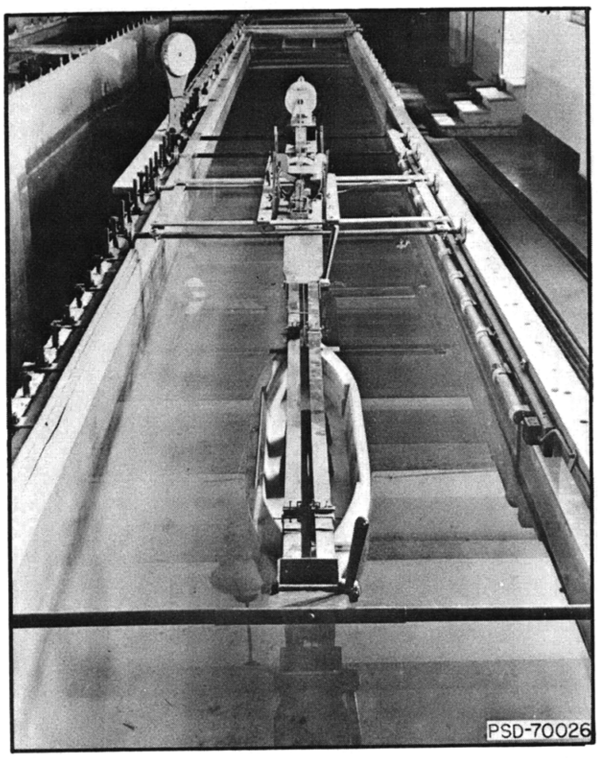
The Hamburg combined shallow water basin and flow channel shares the use of the double-cantilevered towing carriage. The water depth is adjustable up to 2.2 feet in the channel of width 12 feet and length 262 feet. When at maximum section, a water flow of 2 knots can be obtained. Studies of the Baltic to North Sea Canal were underway at the time of visit to Hamburg. The flexibility to adjust the channel dimensions, water speed, and model speed in a facility of this kind is a material advantage in restricted waterway experiments.

The flow channel at Paris has large stilling reservoirs both upstream and downstream of the channel to stabilize end conditions. Water is transferred between reservoirs by 4 hydraulic pumps, located low in the circuit. A water velocity of 12 knots can be obtained when the channel area is about 10 square feet. Windows in the channel sides are provided for observation.

The National Physical Laboratory has reached the final design stage on a circulating water channel with a test section about 6 feet wide and 4 feet deep, and with a maximum water speed a little below 4 knots (9). Initial model studies were made in the Cambridge University Engineering Laboratory under the sponsorship of the British Shipbuilding Research Association.

The Institute of Naval Architecture at the University of Genoa has a new circulating water channel now being calibrated, Figure 24.

In Japan, a new horizontal loop flow channel at the Technical Research Laboratory of the Hitachi Shipbuilding and Engineering company has a windowed cross-section 4 feet square. Calibrations are said to show velocity fluctuations less than $\pm$ 1 per cent up to 3.5 knots; the channel is already in use studying rudder action in a propeller race. It is understood that the flow circulating channel at the rebuilt Mitsubishi Experiment Tank, Nagasaki, has a measuring section 4 feet wide by 2.6 feet deep and a water speed of 4 knots.



—Courtesy Professor Ing. Alfio Di Bella

Figure 24. New Circulating Water Channel Nearing Completion at the University of Genoa. Apparatus for graphically recording the model resistance appears on the centerline of the right leg of the channel.

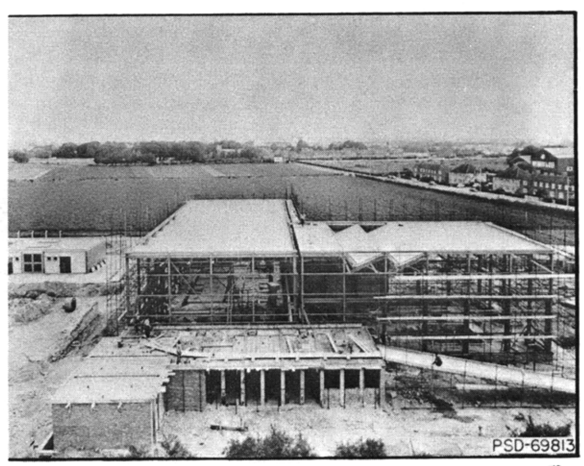
A most unusual flow channel has recently been built at the DeVoorst Hydraulics Laboratory, located below sea level near Emmeloord on one of the remarkable polders of the Zuiderzee works. Here literally is a wind tunnel over a model basin. The basin is 328 feet long, with a width of 13 feet and depth of 2.5 feet. Air flows in a closed vertical loop at velocities over the water surface up to 40 knots. When this unique facility was observed in operation, the variation of wave height, length, and shape with fetch were strikingly apparent.

CAVITATION TUNNELS

New variable pressure water tunnels are characterized by greater versatility, size, and attention to air content. The function of resorbers is to redissolve entrained air bubbles before they return to the test section. Following the lead of the Hydrodynamics Laboratory at the California Institute of Technology (25), many of the new cavitation tunnels are incorporating some form of resorber.

In the new water tunnel under construction at the National Physical Laboratory (9), an exceedingly deep resorber circuit of large volume is being incorporated in order to provide generous pressure and time encouraging air to redissolve. In fact the lower horizontal leg of the tunnel circuit is 180 feet below the test section and has a length of 87 feet. The steel tube below ground, from 10 to over 13 feet in diameter, is grouted into concrete rings.

Pressure in the 44-inch circular closed-throat test section of the NPL tunnel will be variable from near 0 up to 6 atmospheres absolute, and water velocity up to 30 knots driven by an 850 HP motor with a vertical shaft to the impeller in the downstream vertical leg. The working section will be at the



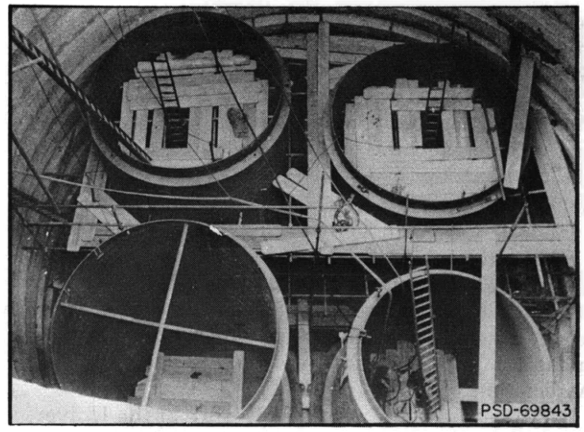
—Courtesy Superintendent, Ship Division

Figure 25. 44-Inch Water Tunnel Building Under Construction at Feltham for the NPL Ship Division. Laboratory offices will be in the foreground, the plant room in the back wing, and the cavitation tunnels between them athwartships.

ground level in a new water tunnel building, Figure 25.

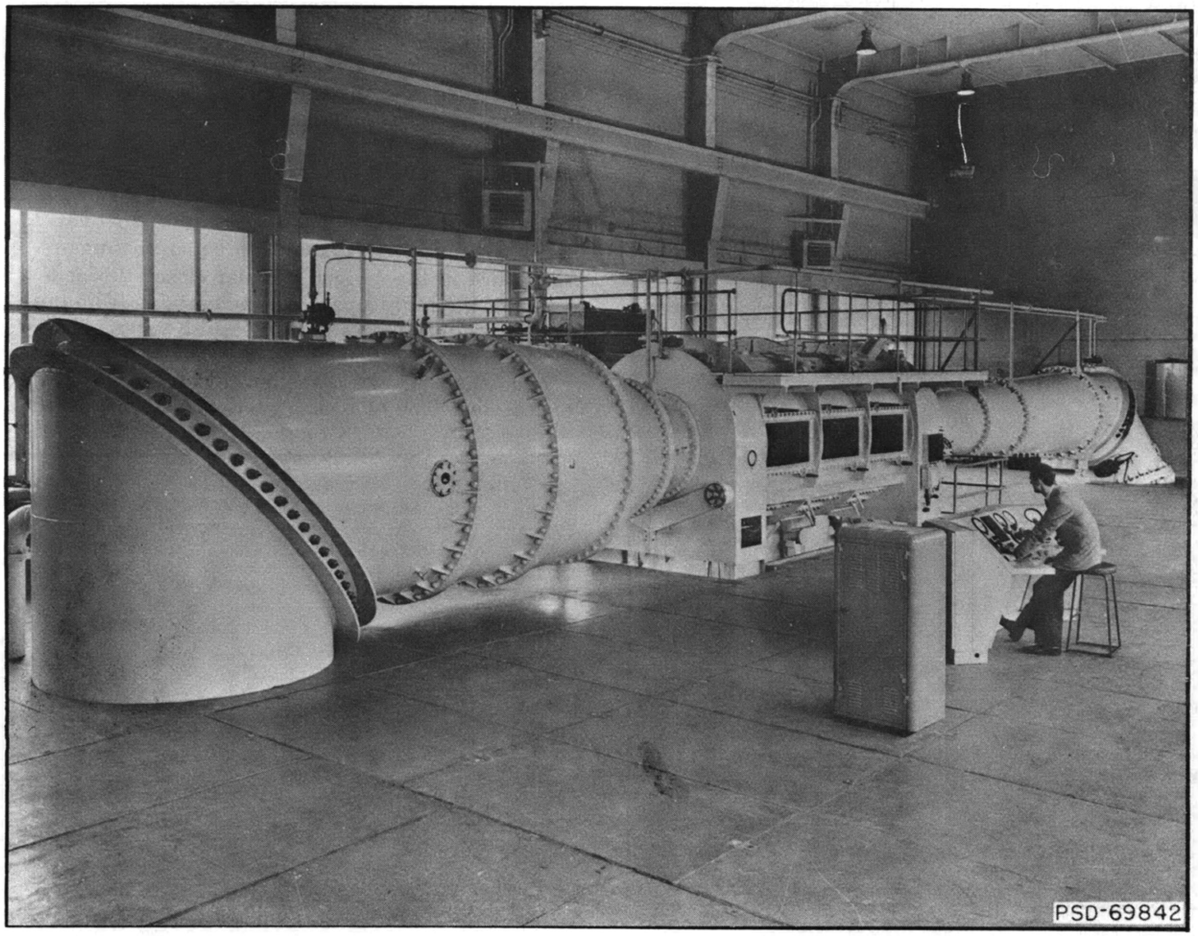
Provisions are being made at NPL for tests of 24-inch propellers in open water, using the same size model as planned for the new cavitation tunnel. An auxiliary carriage, to be towed by the existing carriage over the high speed basin at Teddington, has been built to carry the large propeller dynamometer.

The new 30-inch cavitation tunnel at the Admiralty Research Laboratory (3) has a 4-pass resorber. The lower left duct in the photograph, Figure 26, supports the variable pitch propeller whose plane of rotation is horizontal to keep it under a uniform pressure head. The 850 HP driving motor is direct connected above the propeller. Water is then impelled down this leg, takes two 90-degree bends then up the upper left leg, then down and up again to the elbow ahead of the test section. Transit time for a bubble through the resorber at maximum water velocity is over 70 seconds.



—Courtesy Mr. F. S. Burt

Figure 26. The Resorber Pit for the 30-Inch Variable Pressure Water Tunnel at the Admiralty Research Laboratory. The pit is 35 feet in diameter and 60 feet deep. Each pass of the tunnel is 11 feet in diameter.

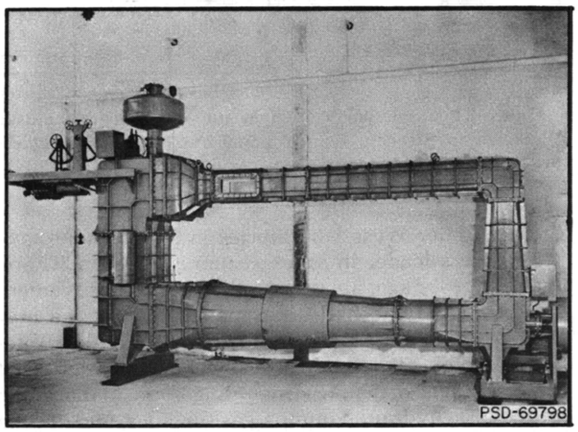


—Courtesy Mr. F. S. Burt

Figure 27. The Completed 30-Inch Water Tunnel at the Admiralty Research Laboratory. The flow direction is from the left in the photograph, past the 3 windows opposite the long working section, and then to an easy diffuser with a generous straight length before making the first 90-degree bend.

The Admiralty Research Laboratory tunnel has an exceptionally long test section, 15 feet equivalent to 6 times the diameter of the jet, Figure 27. Stability of flow, constancy of pressure, and greatly minimized wall effect are attained throughout the speed range up to 36 knots by a slotted wall working section. Slotted walls in water tunnels are new, and the Admiralty Research Laboratory was a prime developer of this arrangement. Slots were said to be really effective only when the test section is long. In this connection, the Superintendent pointed out that a working propeller is a long body and that a long test section is needed to treat it properly. Pressure in the test section is adjustable from about 0.1 to 3.0 atmosphere absolute. Principal instrumentation is by strain gages within the models under test.

The cavitation tunnel at the very modern Shipbuilding Laboratory of the Delft University of Technology (12) has a test section 11 inches square in which a water velocity up to 18 knots is obtained by a 20 HP impeller hydraulically varied up to 700 RPM, Figure 28. The propeller shaft is in the down-

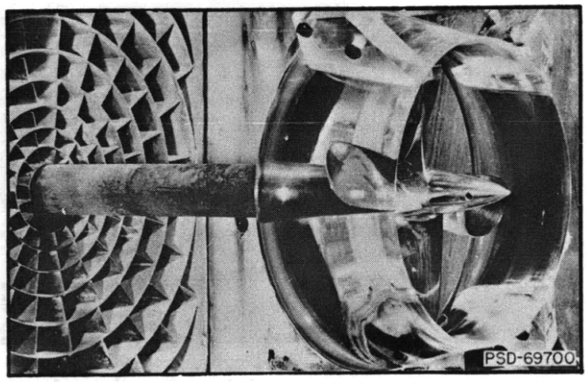


—Courtesy Ir. Jelle Gerritsma

Figure 28. Delft Variable Pressure Water Tunnel. Developmental work for the variable wake tunnel at Wageningen was accomplished here.

stream direction, as in the ship, and propeller model measurements are taken up to 3000 RPM and 4.3 HP. These conditions are obtained with the conventional guide vanes and honeycomb in the elbow ahead of the propeller position. The Delft tunnel was utilized by the Netherlands Ship Model Basin to develop a flow regulator to simulate circumferential as well as radial wake variations over a propeller disc. An alternate elbow ahead of the test section was divided essentially into 146 elements, the flow through each of which could be regulated. A rotating rake with 13 pitot tubes enabled a rapid velocity survey to check the desired velocity distribution. Another development at Delft is a new test section, about 6 inches wide, in which a 2-dimensional propeller profile can be moved transversely to simulate a propeller blade in circumferentially varying wake.

The variable wake cavitation tunnel at the Netherlands Ship Model Basin becomes another classic first for that ingenious laboratory (26). The test section is circular, 16 inches in diameter, with a slotted wall to reduce boundary effects, Figure 29. With

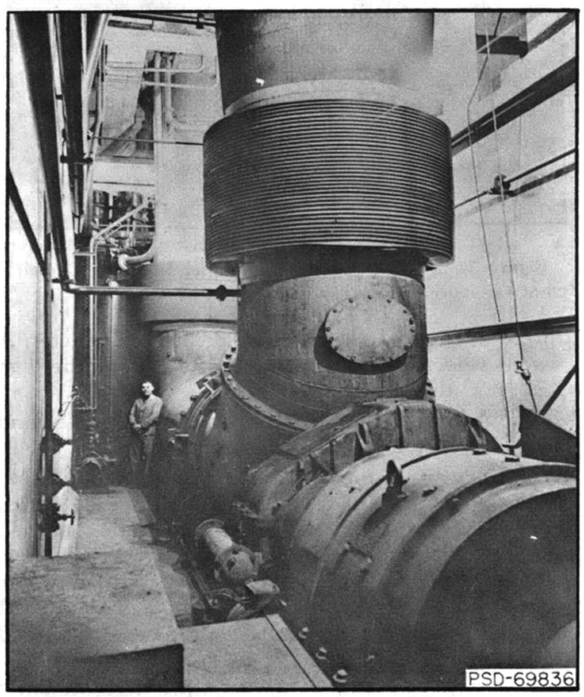


—Courtesy Dr. W. P. A. van Lammeren

Figure 29. First Variable Wake Variable Pressure Water Tunnel, Developed by the Netherlands Ship Model Basin. Flow is individually controlled through each of the ducts to the left in the photograph; the propeller is being tested in a nozzle which has been made of plastic so the flow can be observed.

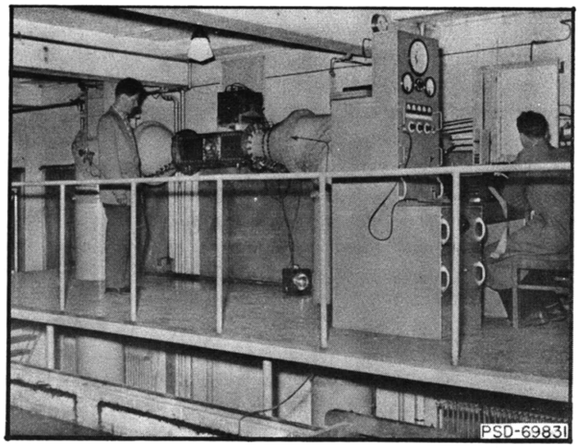
partly closed flow regulator, the minimum cavitation number is about 2, and the maximum water velocity about 12 knots.

The Paris cavitation tunnel, Figure 30, has a closed



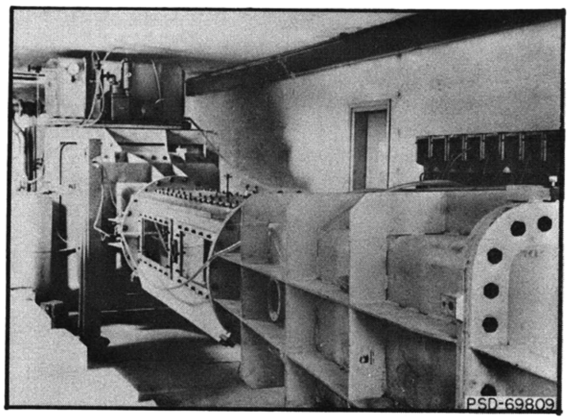
—Courtesy of the Director

Figure 30. Lower Loop of Cavitation Tunnel at the Paris Model Basin. The bellows filter vibrations that may arise from the impeller driven by the large motor in the foreground.



—Courtesy Professor J. K. Lunde

Figure 31. Norwegian Tunnel Model at Trondheim. In this arrangement, flow conditions are being studied in an exceptionally short diffuser section to the right of the flexiglass test section.



—Courtesy Dr. Hans Edstrand

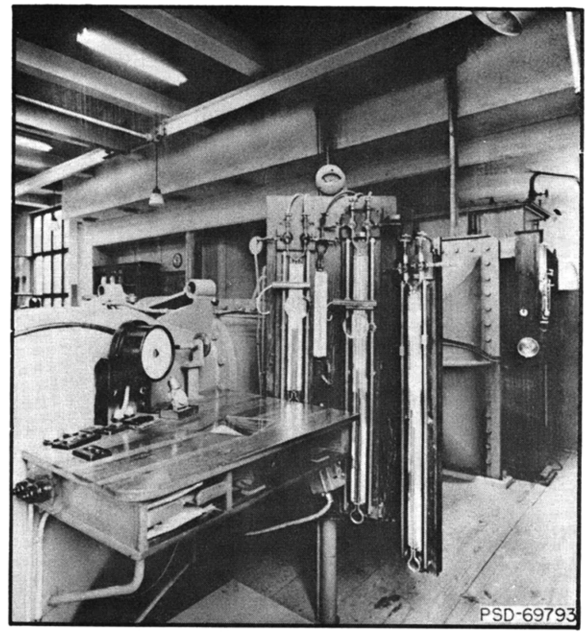
Figure 32. Swedish Cavitation Tunnel Recently Completed at Göteborg.

throat of clear plastic about 36 inches in diameter. A water velocity of 30 knots is attained in the test section of this tunnel.

The Admiralty Experiment Works has erected and housed a very large cavitation tunnel (4).

In Norway at the Trondheim Ship Model Tank, experiments are underway on a small tunnel to gain experience for a proposed large cavitation tunnel. The present facility, Figure 31, has a basic 8-inch diameter closed jet working section with a water speed of 20 knots, and two alternate slotted wall arrangements with maximum test speeds of 10 and 24 knots respectively.

The Swedish State Shipbuilding Experimental Tank at Gothenburg has recently added to its excellent facilities (27) a new variable pressure water tunnel, Figure 32. The Kristinehamn tunnel of KMW, Figure 33, continues its outstanding propeller research.



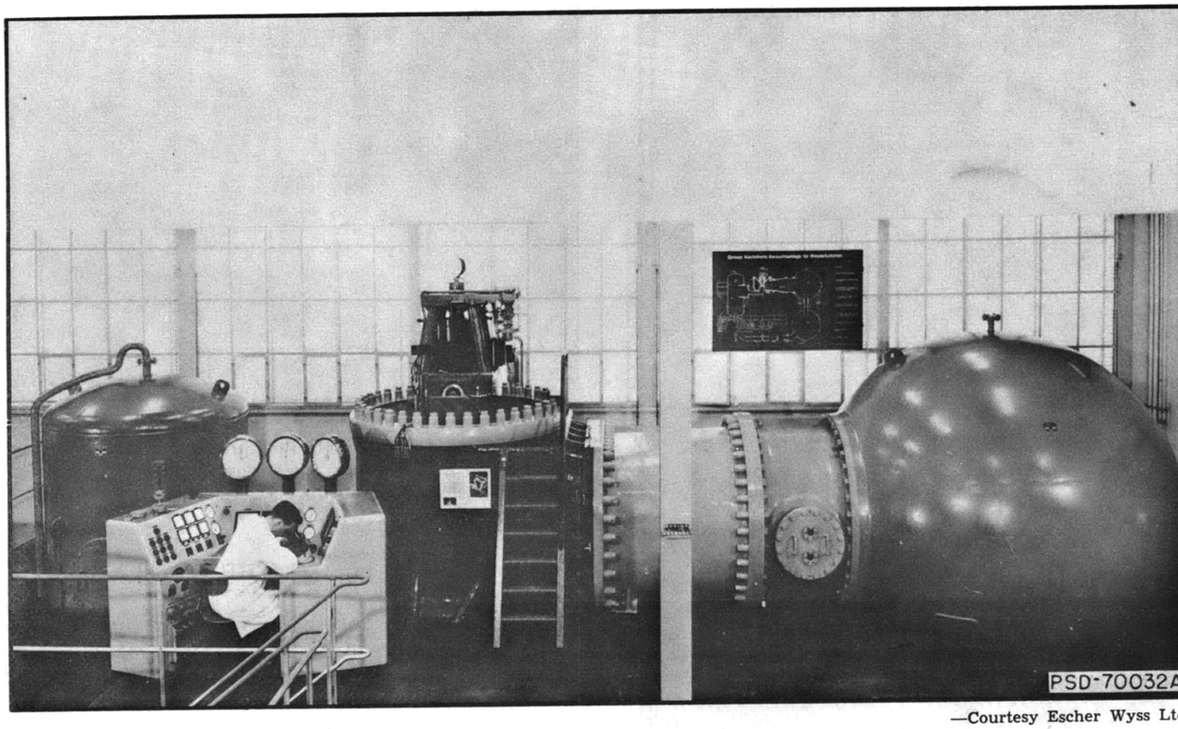
—Courtesy Chief Engineer Lennart Pehrsson

Figure 33. Cavitation Tunnel at the Karlstads Mekaniska Werkstad in Sweden. Control panel and measuring devices are in the foreground.

The Escher Wyss laboratories in Switzerland have long been a leader in hydrodynamic research. There, over 30 years ago, air was used as a more convenient fluid for studying hydraulic models, a practice now widely applied in ship model research. The laboratories support high quality design and production of diverse naval machinery including controllable pitch propellers, hydraulic pumps, gas turbines, and in time perhaps gas cooled reactors.

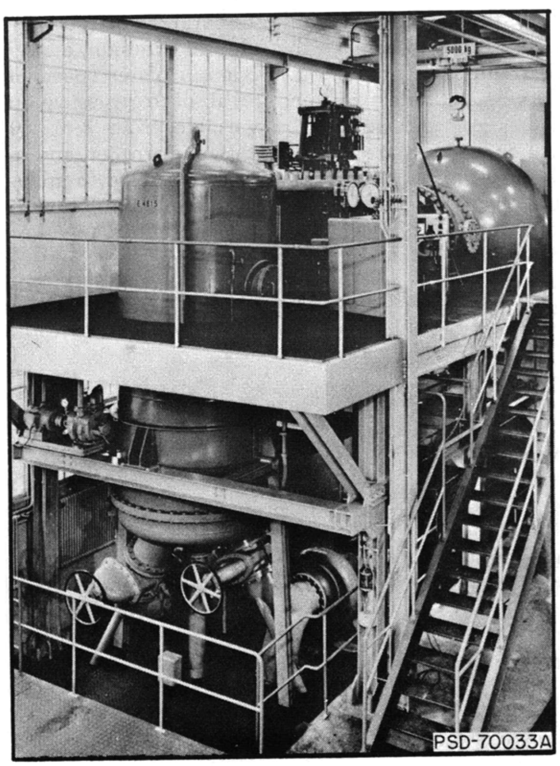
To permit cavitation observations at higher Reynolds numbers, a large variable pressure water tunnel was added in 1956 to the laboratory facilities of Escher Wyss (28). A single console, Figure 34, contains all operating and measuring controls, including the eyepieces for two optical systems for remote observation of cavitation from two directions. The 450 HP dynamometer on top of the test section has hydraulic transmission to the control console where the torque is weight-balanced. Two 400 HP driving pumps, Figure 35, will deliver against a pressure head of over 300 feet; however, the heavy test section withstands the static pressures so that the spiral casing of the model can be of light construction. At the time of visit to Escher Wyss, a model turbine runner test first showed striking cavitation swirls along von Karman vortex streets, and then was carried up to runaway cavitation conditions.

The Spanish cavitation tunnel at El Pardo is essentially the same design as the large tunnel at the Netherlands Ship Model Basin, together with a number of detail design alterations learned by con-



—Courtesy Escher Wyss Ltd.

Figure 34. New Cavitation Tunnel at the Escher Wyss Laboratories. From the pressure sphere, water flows to the left, through the hydraulic turbine model under test, to the tail water cylinder.



—Courtesy Escher Wyss Ltd.

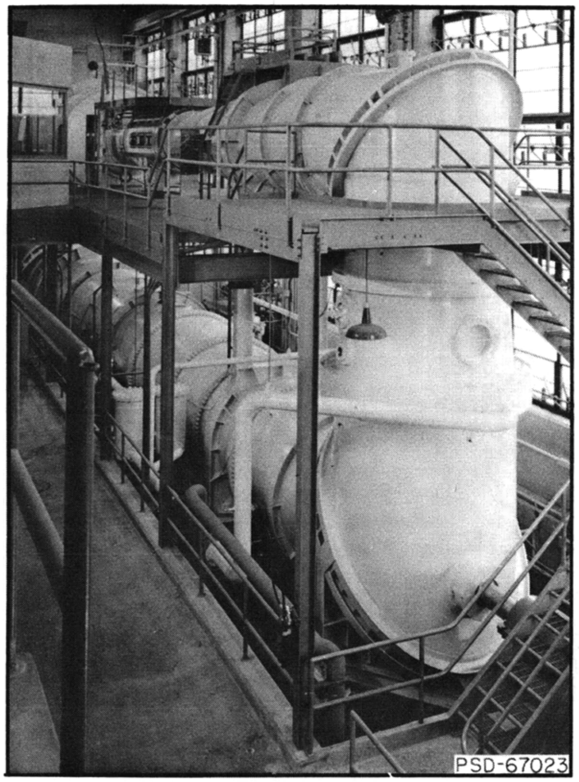
siderable operating experience at Wageningen. The El Pardo tunnel, erected in 1951, has a test section 36 inches square with rounded corners and an impeller motor of 300 HP.

The King's College tunnel was made from parts of a flow facility built originally in Germany for acoustic tests on underwater weapons (29). Its well-designed conversion to a cavitation tunnel provided the largest tool available for propeller research and it has been exceptionally well used. The 12-foot long test section for this tunnel, following a 5 to 1 contraction, is 40 inches high and 32 inches wide with rounded corners.

In Yugoslavia, a new cavitation tunnel, with a test section about 40 inches square, is currently being erected at the Zagreb Shipbuilding Research Institute. Interchangeable test sections will be provided.

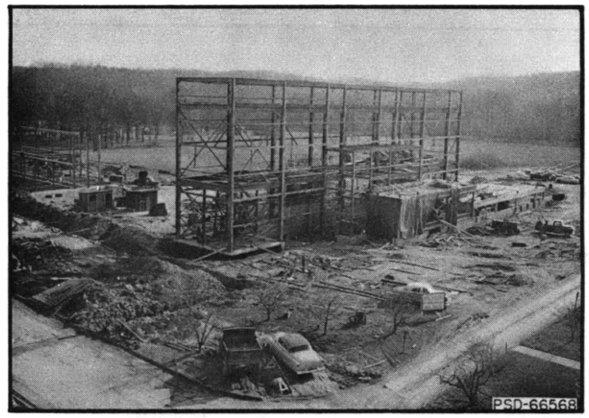
Vospers Limited in Great Britain, long a leader in the development of high-speed small craft, is understood to have built recently a cavitation tunnel with a 20-inch square test section. This firm will no doubt make creative use of this facility in experiments on high speed propellers, with both axial and angular inflow, and in research on rudders and stabilizing fins.

Figure 35. Escher Wyss Cavitation Tunnel. From the tail cylinder, water is valved to two radial pumps connected either in series or parallel, thence to the bottom pressure sphere, and via a venturi to the top pressure sphere. Flow direction can be reversed for models operated as pumps.



Courtesy of the Director

Figure 36. Largest Water Tunnel in the United States, Located at the Ordnance Research Laboratory, Pennsylvania State College.



—Official U. S. Navy

Figure 37. 36-Inch Variable Pressure Water Tunnel Under Construction at Carderock. The resorber pit is 70 feet deep in bed rock lined with stainless clad steel.

At the Ordnance Research Laboratory located at Pennsylvania State College, a large tunnel was completed in 1950 for the purpose of testing complete self-propelled models of underwater bodies under controlled conditions (30). In the 48-inch diameter working section 14 feet long, water speed can be continuously varied to selected velocities up to 48 knots, Figure 36. The 95-inch, 4-bladed, adjustable pitch impeller is driven by a 2000 HP variable speed induction motor.

The 36-inch variable pressure water tunnel now under construction at the David Taylor Model Basin (31) will have a vertical double-pass resorber with an outer cylinder 25 feet in diameter extending 70 feet below the ground elevation. It is estimated that bubbles entering the resorber with diameters of 0.015 inch or less will be reabsorbed into solution. Design of the new DTMB cavitation tunnel was materially assisted by tests of a 1/6-scale pilot model at the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota. In the full scale version, a 2880 HP pump will produce a maximum water speed of 50 knots in the test section. The absolute pressure on models under test will be variable from 2 to 60 pounds per square inch. Both an open jet and a closed jet test section are being constructed. Removable propeller shafts from both upstream and downstream directions will provide flexibility, together with independent dynamometer drives for counter-rotating propellers. It is expected that the DTMB tunnel, Figure 37, will be completed by mid-1958.

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Apologies are made for failure to mention any new facilities unknown to the author, and for any unintended emphasis disproportionate to the importance of the facilities briefly described.

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