Making the Best Use of a Small Ship Model Tank

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Summary:

Small ship model tanks are more often improvised than designed. Nevertheless some fairly basic analysis and design becomes necessary before any worthwhile work can proceed.

What is the minimum size of tank worth developing? How is tank size linked with "scale effect", the use of drag reducing additives, tests on self-propelled models and on models of high speed craft in ocean waves? What physical quantities are of major interest? How should these be measured? Is a towing carriage necessary? What deviations from "uniform motion in a straight line" are likely? What causes irregular motion? How can it be reduced? What effect does it have on measurements? What level of irregularity can be tolerated? How can the output from measuring instruments be processed to reduce the effects of such interference? These and other questions are discussed and some answers are provided. Examples are drawn from experience at the University of Sydney with a 57 metre tank. Reference is made to yacht model tests, extra resistance in waves, studies of wave pattern drag and rating current meters.

The author indulges in some day-dreaming to the extent of considering the ship model laboratory he would like to see in Australia.

Review of the Hydrodynamic Limitations of the Small Ship Model Tank

> Some ship model tanks were designed, and built to plan and specification; others, mainly the small ones, just grow'd like Topsy.
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> Apologies to Harriet Beecher Stowe.

Many of the small tanks throughout the world were built with whatever resources might be available, the chief being enthusiasm, by men with a true academic interest in discovering how to build better marine vehicles. Typically these men found space in an existing building and made the best of it. They were aware of the deficiencies, but went ahead, facing the problems as they arose. Such was the beginning of the tank at Sydney University where a concrete return channel for a flume in the Hydrodynamics Laboratory had been made in a form which would permit ship model tests on a very small scale. The enthusiasm was provided by the late George G. McDonald, Professor of Mechanical Engineering, and his successor, P.T. Fink, now Dean of Engineering at the University of New South Wales. The channel is 57 metres long, 2.7 metres wide and is conveniently filled with 1.2 to 1.5 metres depth of water. The panel of experts responsible for the design of the laboratory made no attempt to provide any other equipment for a ship model tank, but from the result it would appear that they had sought some advice on the smallest feasible dimensions.

It might be as well to interpolate here a brief description of a ship model/test. While such tests may be a many and varied as the questions which can be asked, one test is basic and typical. A model of a bare hull of a ship is towed through stationary water in a laboratory, the drag and the speed being measured. The model speed is scaled down by the square root of the length ratio. The drag of the ship, in these circumstances, is roughly the drag of the model multiplied by the ratio of ship displacement weight to model displacement weight. As a refinement, some allowance is made for the fact that viscous drag on the model is greater, in proportion, than the viscous drag on the ship. The result is used to estimate the size of engine required to propel the ship. The models vary in size from one to ten metres long requiring tanks from fifty to a thousand metres long. Greater accuracy is claimed for tests on larger models in larger tanks.

Faced with an existing concrete channel, one can consider the largest model which might be tested without risking serious errors due to "reflections" of flow fields off the tank walls and floor. A rather crude and very inaccurate picture is presented by saying that due to the "blockage effect" of the model in the limited tank cross-section the relative water velocity past the model is higher than in the open water case. This venturi effect leads to an excessive drop in water level abeam of the model which aggravates the blockage effect. Eventually a transverse wave is formed which is more a property of the channel than of the model. The correct analytical solution to this problem is exceedingly difficult, but short-cut methods combined with systematic experiments have provided guidelines for model size and for making small corrections to the test results. The most important limitation is the need to avoid excessive excitation of unwanted modes of wave formation, and practical experience suggests that the "depth Froude number" defined as $F_D \equiv v/(gd)$ should not be much greater than 0.3 and that the model immersed cross-section area should not be much larger than one percent of the tank cross-section. Here v is the model speed and d is the depth of water. At Sydney g is 9.797 metres seconds^{-2}. (In channel flow, if F_D exceeds 0.6, the water surface seems to become quite unstable and if F_D approaches 1.0, surface effects become rather spectacular. Here v is the water velocity.) The basis of ship model tests is that the model is run at the same value of "length Froude number", defined as $F_L \equiv v/N(gL)$, as the ship. Here L is usually the LBP, the length between perpendiculars. For a fast displacement vessel operating at $F_L \simeq 0.3$, the limiting length of the model becomes L = d = 1.3 metres, say, for the Sydney University tank.

For $F_D < 0.3$, surface disturbances produce "deep water waves" characterised by the dependence of crest velocity, c, on wavelength, λ, according to the relation: $c = \sqrt{(g\lambda/2\pi)}$, and the energy propagation (group) velocity equal to half the crest velocity. From these observations it follows that the half angle of spread of energy from the bows and course of the model will be 19° 28'. A little elementary trigonometry shows, that for a 1.3 metre model on the tank centre line, the wave energy reflected off the walls of a 2.7 metre wide tank will clear the stern of the model by 6 metres or so. This is more than adequate and for a vessel designed to operate at $F_L = 0.15$, a rather larger model could be used provided its cross-section did not greatly exceed one percent of the tank cross-section.

If the model speed is raised to around 3.3 metres per second so that $F_D \simeq 1.0$, then some spurious effects can be expected. However water craft do not operate efficiently at $F_L \simeq 1.0$ and so this is not often a worry. It has been shown that the performance of planing hulls is not very sensitive to the value of F_L as such, provided $F_L > 1.5$, and it may be inferred from this observation that the form of the trailing wave system does not matter much, even when the waves tend towards the shallow water type where $c = \sqrt{(gd)}$ and energy propagation velocity tends to equal crest velocity. Provided v is markedly greater than $c = \sqrt{(gd)}$ and blockage ratio (= model cross-section area ÷ tank cross-section) is less than, say, one percent, the transverse wave across the tank abeam of the model will not be excited. In fact transverse waves of any kind will be left behind. On this basis models of high speed craft may be tested at speeds where F_D is greater than, say, 1.2. Incidentally this may not be unrealistic, for most high speed craft operate on relatively shallow water.

If it becomes necessary to test a model in the range of F_D between 0.5 and 1.2, say, then it is very important to keep the blockage ratio quite small and to consider methods for making blockage corrections. A number of such methods have been published and are reviewed in the proceedings of the 1975 International Towing Tank Conference. The use of a blockage correction is, of course, recommended practice for all ship model tests. The next consideration is the boundary layer around the hull. By definition this is the layer of water which has partly or wholly lost its momentum relative to the hull due to the action of viscous and turbulent shear stress. A boundary layer is said to have a displacement thickness, δ^*, within which the water has lost most of its momentum, and outside which there is still some boundary layer wherein the water has lost some of its momentum. The flow in the boundary layer may be laminar at the bows, but will become turbulent around the beam. The extent of laminar flow on a ship is negligible, but is likely to be important on a small model. The thickness, δ^*, increases from stem to stern where it streams off to form the wake. The order of magnitude of δ^* at the stern of a ship is L/300, and at the stern of a model is L/100. The order of magnitude of the eddies in the turbulent boundary layer is, of course, δ^*, and should not be confused with the eddies resulting from flow separations. These are larger by several orders of magnitude.

As nearly as possible the boundary layer around the model should be "similar" to the boundary layer around the ship. It should behave in a "similar" manner. Boundary layers are described principally by a Reynolds number defined as $R_L \equiv vL/\nu$, where ν is the kinematic viscosity of water with magnitude of order 10^{-6} metre^2 second^{-1}. Displacement thickness varies as $R_L{}^{-6}$ so for a 1.3 metre model of a 130 metre ship, where R_L is too low by a factor of 1000, the model δ^* is around 1/30 of the ship δ^*, whereas the linear scale ratio calls for 1/100. Thus the model boundary layer is three times too thick. This has two effects. For wavemaking the ship or model dimensions appear to be increased by δ^*. This, in proportion, tends to increase the model wave making. The water in the boundary layer, having lost its momentum, responds readily to pressure gradients parallel to the surface of the hull, and in doing so, partially short-circuits the waves. To this extent wavemaking is reduced, more so in the model than the ship. Fortuitously one effect more or less balances the other and the results obtained from a 1.3 metre model test are not very different to the results from a 5 metre model test. However the curves of ship drag coefficient versus F_L derived from small and large model tests often show highly significant differences in shape. The humps and hollows in the small model test curves are usually much less pronounced than in the large model test curves. Dr. Lawrence J. Doctors, working in this tank, tested a strut like model with and without additional water bled into the boundary layer. The effect on wavemaking, as determined from measured surface profiles, was very small for quite drastic increase in boundary layer thickness. The present author, using another of Doctors' mathematical models and a much thinner "plank" of the same length and draught, increased the boundary layer on both by similar sets of leading edge roughness elements. He found the difference in drag, largely the wavemaking component, to be markedly reduced by excessive boundary layer thickness, and the humps and hollows to be smoothed out. Pitot tube traverses in the wake of Doctors' model showed evidence of remarkable boundary layer migration. In the high F_L region, around $F_L = 0.3$, the boundary layer was spread out as a woolly fan on top of the water, radiating from the stern of the model. This model had the form $y = 0.0435\ (1 - (x/0.503)^2)(1 - (z/0.229)^2)$ with L = 1.006 m., B = 87 mm., and T = 229 mm., while the corresponding plank had a beam of B = 20 mm. for the same length, L, and draught, T. Such a shape undoubtedly favours migration because the boundary layer is subject to a strong vertical component of pressure gradient over the middle part of the model. Wake traverse results showing similar tendencies have been noted in the literature.

In addition to these effects on wavemaking the ship model tank man must consider how the skin friction on the model differs from that on the ship. Froude's proposition was that the difference between ship skin friction coefficient and model skin friction coefficient was roughly the same as the difference between the skin friction of a ship size plank and the skin friction of a model size plank, at corresponding speeds. This proposition is, at best, an approximation, and generally is somewhat inconsistent with the predictions of boundary layer theory. It has worked well enough for large model tests over the past eighty years in spite of the obvious dissimilarity in boundary layer thickness. But when this dissimilarity is exaggerated by the use of small models, and, at the low values of length Reynolds number encountered, qualitative differences also show up, then the position is rather doubtful. Unless special action is taken, the boundary layer over a small model is largely laminar compared with that over a ship, which is wholly turbulent. There is no similarity between the behaviour of laminar and turbulent boundary layers and no basis for model tests exists. To get over this difficulty, studs are fitted to the bows of ship models to promote small scale turbulence such as would be found in a turbulent boundary layer. If the studs are set a distance, X, abaft the leading edge, then their success depends on a local Reynolds number defined as $R_x = vX/\nu$. Roughly, for the shape of the bow water lines also have some effect, the studs successfully promote a turbulent boundary layer if $R_x > 60000$. If R_x is much less, the disturbance made by the studs is damped out by viscostiy, and the boundary layer remains laminar over a large and indeterminate part of the model. Since laminar skin friction is very much less than turbulent skin friction, this lack of definition renders drag measurements rather meaningless. For 1.3 metre models, the studs of around 3 mm. diameter, 2.6 mm. height, spaced vertically 30 mm., are set 120 mm. back from the leading edge. This gives a determinate area of turbulent flow abaft the studs and a displacement thickness over this area which is about that which would develop if turbulence started right at the leading edge or stem of the model. This is not a good dynamic model of the ship boundary layer, but seems to be about the best option available. However, 1.3 metre models cannot be run at F_L less than about 0.14, otherwise the studs will fail and the results will be meaningless. Thus models smaller than 1.3 metre long or a tank smaller than 1.3 metre deep by 2.7 metres wide are not really practical. Apart from the one percent blockage ratio rule, which is rather elastic, the width is needed for longer models to run at the lower values of F_L without wave energy reflected off the tank walls passing too close to the stern. The length of the tank is set by the time taken for the flow and wave fields to settle down, for the measuring systems to settle down, and by the need for adequate margins on accelerating and braking distances. These factors will be discussed later, but it may be fairly stated that 57 metres is just about the lower limit of usefulness.

For many years a standard joke has been the suggestion that boundary layers could be dynamically modelled if the tank were filled with mercury rather than water. Because mercury has a low kinematic viscosity, Reynolds numbers could be matched by a proper choice of scale ratio. Around a decade ago it seemed that a suitable alternative liquid had been devised. Skin friction in water is quite dramatically reduced by chemical additives at concentrations less than 30 parts per million. Generally speaking, reduced skin friction means reduced boundary layer displacement thickness. Some natural gums, polysaccharides produced by algae and synthetic poly-ethylene-oxide show this effect quite strongly. Experiments in a few very small tanks have produced interesting results. Certainly the boundary layer displacement thickness over the model can be reduced to something like the sealed thickness and one may be tempted to think of this as a method offering large tank performance to the small tank. Unfortunately, on examining the proposal more carefully, there appear to be too many uncertainties. The remarkable reduction in shear stress is only available in turbulent boundary layer flow and only after the shear stress exceeds a certain threshold. The additives have negligible effect on kinematic viscosity and therefore do not alter Reynolds number. The additives do not assist in securing early transition from laminar to turbulent boundary layer flow. The additives become seriously degraded with use and with time, making it rather difficult to maintain water with a constant friction quality. If a laboratory has been contaminated with additive, it is very difficult to remove it completely and get back to normal operation with water of the standard friction quality. This alone is enough to cause tank superintendents to be very wary about introducing any such material. If such a scheme were adopted one would have to face some awkward questions. Is the model boundary layer dynamically similar to the ship boundary layer? Are there laws for predicting ship performance from model results in treated water which give better accuracy and reliability than the methods at present used with plain untreated water? If a model propeller is tested in the wake of a model hull running in treated water, will the results be more meaningful than if untreated water were used? Apart from displacement thickness, the similarities, if any, are overshadowed by the dissimilarities and uncertainties. So far no ship model tank seems to be using the additives for routine work. Naturally, every ship model tank superintendent is watching the position carefully. The general use of some additive at some time in the future is not unlikely.

Seakeeping tests are a normal part of the work of a ship model tank, and the Sydney University tank is equipped with a wave making machine. This is limited to head and following seas and works quite well for displacement hulls or planing hulls in choppy seas. However the case of a planing hull on an ocean swell soon shows up the inadequate length and depth of the tank. The waves are shallow water waves and therefore it is not possible to scale correctly both crest velocity and wavelength. One ordinarily scales wave encounter frequency. In these circumstances the wavelength lends to approach the length of the tank, the wavemaking machine fails to produce realistic wave contours, and the model has no chance to settle down to a steady oscillatory response to the waves.

From these remarks it will be apparent that one cannot claim that predictions based on small models are accurate. Even large tanks have produced some notable failures while using large models where the Reynolds number gap, the ratio of R_L for the ship to R_L for the model, is smaller by a factor of eight or so, say 300 as against 2400 for the small tank. So what is the role of the small tank? It is quite useful for teaching principles of naval hydrodynamics and laboratory techniques, and for many small university tanks, this is their main justification. They make very good current meter rating tanks and this may, in itself, justify the existence of some tanks. Although this work may be a mere "chore", it is nevertheless an important link in a chain of events leading to engineering structures of even greater capital cost than ships. But of more interest than these things is the initial evaluation of novel ideas. The cost of "trying something" in a small university tank is not high, and therefore a member of the academic or research staff can test an idea without having to formally justify the cost by a detailed cost/benefit analysis. He would be obliged to act in a responsible manner, but the fact that he had a question and desired an answer would generally be sufficient. This would never do if he wished to interrupt the flow of work in a big tank. Even if the big tank were idle, there would be the usual fears of "setting a precedent". Consequently large establishments are not noted for the amount of pure research attmepted.

Novelties are not limited to entirely new concepts, but may be in the form of modifications to existing ships. It may then be a sound proposition to build a small model of the ship, test and verify the model, modify the model, test again, and apply the difference to predicting the effect on the ship. If the modification is not too greatly affected by boundary layer phenomena, that is to say, by Reynolds number dependent factors, then the procedure is sound and the prediction is likely to be accurate. Undoubtedly yacht model tests fall into this category, for the critical comparisons are between model and model and one hopes that the same trends will show between ship and ship. The first step is to build a model of the yacht with the best racing record for which reliable plans are available.

In the developmental design of small craft a tank close at hand may be worth two at the other side of the world. Not only may the costs be a better fit to the budget, but the time factor may be more favourable. These factors can compensate for any loss of accuracy in predictions. Tank tests are not required for most small craft because there is adequate information available which is more reliable than individual model tests. However novel features frequently show up and the effects of these can be quite unexpected. Model tests, if only to act as insurance, are available at a very low premium.

An idea tested in a small tank, and found to be valid and cost effective, can always be presented to a large tank for verification. This is a logical way to conduct an investigation. In fact some of the large ship model tank complexes have small tanks for use in this way. However it is not as easy to cut cost barriers in these establishments as it is in the relatively informal atmosphere of a university laboratory.

One cannot conclude a discussion of the small ship model tank without mentioning self propulsion tests. Here the model is powered by an electric motor equipped to measure tail shaft torque, speed and thrust of a model propeller. The problems of laminar versus turbulent boundary layer flow apply to the propeller, and a laminar boundary layer leads to a much inferior propeller performance. Even with studs it is not possible to model a propeller if the model mean chordal Reynolds number is less than 10^6, effectively preventing self-propulsion tests being done in a small tank. Apart from this, one of the major points of interest is the interaction of the propeller and the wake, and if this is three times too thick to scale, the tests become largely meaningless.

The Towing Carriage

To be, or not to be:
That is the question:

Apologies to Shakespear's Hamlet.

Some small tanks had no towing carriage and examples are Newport News, Fort Steyne and Massachusetts Institute of Technology. Others had only miniature carriages like the tanks at Stevens Institute, New Jersey. Some, like M.I.T., started without a carriage, but added one later. A free running, radio controlled, battery powered, self propelled model carry appropriate measuring equipment relaying propeller shaft torque, speed, thrust, hull speed and acceleration components by radio links back to shore based recorders, can operate on any sheltered stretch of water. Alternatively a bare hull model can be towed by a length of fishing line. Drag can be measured by a miniature drag recorder in the model or by a specially calibrated miniature winch. Speed can be measured by timing the model as it cuts light beams projected across the tank on to photo-electric devices, or by timing the revolutions of the winch drum. Why, then, go to all the trouble and expense involved in providing a towing carriage?

The answer to this question is a matter of versatility, productivity and convenience rather than of necessity. Experience in running a tank shows that the addition of the carriage, track and drive, representing only a fraction of the cost of the building space occupied by the tank, leads to a several fold improvement in the value of the work done. The tests which can be done without a carriage can be done far more easily and quickly with one. Even self propulsion tests are easier and less expensive when flexible power and signal wires from the carriage replace the batteries and complex radio equipment in the model. By way of contrast it is hard to imagine current meter rating without a carriage, tests on non-buoyant structures or yacht model tests where a side force must be applied.

The carriage is more important as a stable platform to carry observers, instruments, power sources and other services, than it is as a means for applying a towing force. To perform the former function it must run straight and level at precisely constant velocity. It must be possible to accurately preset the velocity at any value over a wide range. The carriage must be very steady, that is to say vibration levels must be low, and oscillatory motion in pitch, yaw, roll, surge, heave and sway must be very small. How is this achieved?

The first, and usually the most expensive step, is to provide a very stable foundation for the track. Usually the tank structure is designed to form a rigid beam to support heavy duty steel rails, but the continuing integrity of such a structure depends on the stability of the ground below. The United States Navy abandoned the large Washington tank when a geological fault became apparent. The N.P.L. tank at Feltham, north of London, was laid on top of an ancient gravel bed, not sunk into it, because this was considered the most stable foundation available. The rails are set in closely spaced adjustable rail chairs bolted and grouted to the top of the tank wall. The rails are adjusted straight and parallel to the still water surface within a tenth of a millimetre. The rails are machined, at least on the top and sides of the rail head. One rail, used for lateral location of the carriage, must be particularly straight and the head of constant width. Thermal expansion is not a problem inside the building. The sun is excluded to avoid a growth of algae in the tank and some effort is made to avoid large changes in water temperature and kinematic viscosity. Therefore the ends of the rails are machined and butted hard together. The level of the rails is checked, in the Sydney University tank, by an eight metre base water level consisting of two brass pots filled with water and connected by transparent plastic tube. The latter feature is most important, for an air bubble in the tube invalidates the readings. A micrometer probe equipped with an electronic visible/audible detector enables a 120 metre circuit to be closed with a mean error less than a tenth of a millimetre. Unfortunately the rail system has never been adjusted to this accuracy, and as it stands at present, leaves much to be desired.

The carriage may be self propelled by electric traction motors or drawn by a winch through flexible wire cables. The latter system means that the carriage is very simple and it is not necessary to provide heavy duty conductor rails operating at dangerous voltages. However the weight of the ropes, sheaves, return pulleys, etc. is quite considerable and all this must be accelerated with the carriage. What is worse, the resilience of the ropes is such that the carriage has a low natural frequency in surging and this mode is poorly damped. The Sydney University carriage is drawn by two wire ropes of 25 millimetres girth, weighs about 500 kilograms, has a natural frequency in surge of 2 hertz with an amplitude in surge around 2 millimetres being commonly observed. This surging seriously interferes with the operation of instruments, particularly the drag dynamometer.

When the Sydney University tank was being equipped, the local expertise in feedback systems was developing, but not firmly established. Therefore electric traction motors were not favoured, and, in any case, the availability of suitable motors in Australia was doubtful. The feed back system was avoided by adopting an electro-hydraulic winch consisting of a synchronous motor, a hydrostatic variable speed unit, (the generous gift of Vickers-Armstrongs,) a four speed spur gear box and a motor truck rear axle assembly with wood lined sheaves instead of road wheels. The last unit provides a differential gear to balance the rope loads and compressed air operated friction brakes for emergency stops. The speed can be preset to about 1 part in 500 and remains constant to better than 1 part in 1000 over the measuring run. The back tensions in the ropes are maintained by travelling pulleys loaded with nests of springs. Because floor space was limited the tensioning assemblies are vertical, self-supporting structures.

The towing carriage at Sydney University consists of a frame made of 50 millimetre O.D. aluminium alloy tube joined by clamps. It is carried on four cylindrical steel wheels and guided by two pairs of steel rollers engaging the head of one rail at the front and at the back of the carriage. Naturally the supporting wheels do not run quite true, but tend to veer off the rails. This causes the wheels to strain the structure until the force exceeds the friction grip of the wheel on the rail. The wheel then slips laterally with a jerk capable of exciting almost any mode of oscillation or vibration in the carriage. This stick slip action certainly excites the 2 hertz surging which is very troublesome. To make the slipping easier and to keep a good surface on the rails, rotary brushes attached to the towing carriage sweep the rails and spread a thin coating of oil and graphite. The National Physical Laboratory in Britain has designed a wheel system which very successfully overcomes this and some other problems, but the resources available to the Sydney University tank are such that this solution is out of reach.

The towing carriage is controlled directly by a large wooden lever attached to the tilting box containing the swashplate of the rotating cylinder barrel type of hydraulic pump. As the swash plate angle is varied, so does the stroke of the pistons vary, and the flow of oil. The stroke of the hydraulic motor is fixed. Therefore the speed of the winch and the towing carriage is proportional to the displacement of the wooden lever. Calibrated adjustable stops are provided which set the steady speed of the test run. Driver training is important because most people who drive a car are tuned to a control which relates thrust to pedal displacement, whereas the large wooden lever relates gear ratio to lever displacement. Therefore the driver must move the lever smoothly while accelerating or decelerating the carriage. Under normal circumstances the friction brakes are not used, but can be brought into action by any one of a number of "panic" buttons installed along the tank. The main circuit breaker is released by the panic buttons and the system fails safe in the event of an interruption to the electric power. The spur gear box is remotely operated by pheumatic cylinders and first gear reduces speed by a factor of forty compared with fourth gear. For some work, very low speeds are needed. On one job the carriage was set to travel 50 metres in 3 hours. The top speed is 5 metres per second. The carriage can be operated semi-automatically by a push button and limit switch system for speed up to 2 metres per second. However a driver in the elevated control box contributes so much to safety and teamwork that the use of extra manpower is more than justified for most work, and especially when classes of students are using the equipment.

It has been convenient to transmit the output of measuring instruments over trolley wires to a shore based recording station. The normal power supplied to the towing carriage is the output of a 2 kilowatt, 50 volt rectifier set while a number of 6 volt dry batteries are used for electronic equipment. Thus risk of electrocution is minimised. Painful experience at another Australian university shows that such risks may not be disregarded.

Many towing carriages have shown a tendency to run away and tank superintendents like to have some back up stopping device. At Sydney University an extra pair of limit switches are wired into the panic button circuit, but it is doubtful if the space available would be sufficient to retard the carriage from full speed.

The power required by a towing carriage is determined by the mass of the carriage, the ropes and sheaves, and the payload, all in conjunction with the acceleration required. The latter depends on the length of the run allocated for acceleration and the top speed required. These tend to be fairly arbitrary decisions, but it must be remembered that very high acceleration causes a major disturbance in in all systems, including the hydrodynamics. Mathematical studies give warning of the persistence of transient effects excited by excessively high acceleration. At Sydney Universtiy the mechanical output of the winch is something like 10 kilowatts, and the design philosophy was based on a notional allowance of 10 metres for acceleration, 20 metres for the steady speed run, 10 metres for retardation leaving 17 metres for the beaches, the wave making machine, the length of the carriage itself and small safety margins. It must be admitted that the weight of the carriage and moving gear exceeded expectations, and it was found that the original notional top speed of 8 metres per second was not practical.

The use of standard aluminium alloy scaffold tubes and couplers in the construction of the towing carriage was aimed at versatility. During its life the carriage has taken on many different shapes to suit the different jobs done, and the ease with which modifications can be made has been very valuable. After a while it becomes necessary to strip off the extra pieces in order to make a fresh start. This homely "spring cleaning" seems to bring out the value of a relatively heavy duty carriage more than an analysis of the job statistics.

Some Problems in Measurement

To consider these "problems" in retrospect is to present a lot of material which the modern engineering student would regard as "text book stuff". At the time, however, it was a matter of learning the hard way and improvising equipment not otherwise available or expensive beyond the funds in hand. In this paper, therefore, the results of many years of spare time effort will be presented very briefly, with a few comments on points which caused special difficulty.

The measurement of speed, at the accuracy required, is best achieved by measuring time and distance. Time markers are generated by a master pendulum and slave clock system, which, in turn, is checked against the Post Office talking clock and radio time signals. Distance marker cams are laid out along the track using a surveyer's tape and these cams engage a microswitch on the towing carriage. These markers are fed to a chronograph to be recorded on a moving paper tape by solenoid operated pens. Careful comparison of the marks on the time and distance traces gives the towing carriage speed. Another system uses two digital electronic timers triggered by photo-electric devices carefully spaced 12.192 metres (40 feet) apart. One timer checks the other. The quartz crystal oscillators of the timers are carefully checked against the master pendulum. One is no worse than 1 in 10^5, while the other is running slow by 3 in 10^5. The timers are usually set to display time interval in milliseconds and speed is calculated, in these modern times, on a procket electronic calculator. For reliable triggering and proper sequencing of the gate open, gate closed, display and reset functions, quite a lot of design and development time went into the photo-electric devices, the signal conditioning unit and the sequence control unit. Buying thousand dollar electronic stopwatches is not enough. They must be fed control signals tailored to fit fairly tight specifications.

All this effort has merely measured the speed of the towing carriage whereas the significant quantity is the speed of the model relative to the bulk of the water. Therefore water movement must be kept under control. The surface disturbance is fairly obvious and is dissipated on beaches at each end and, often, along the sides of the tank. The viscous wake following the model is rather confused after the slow return run and is rapidly lost by turbulent mixing. However it is possible to set up a slow drift of the surface water along the tank while a balancing back flow occurs near the bottom of the tank. The interface between these two flows should be quite unstable so that the whole body of water becomes locked together by very low velocity large scale turbulent mixing. However thermal stratification can make the system stable and it is wise to take some action to break up the flow. Stirring the tank with a paddle before starting the day's work is one way of stopping the surface drift. Stretching impervious curtains across the tank between test runs is another way. During the run, the weighted curtains are released and sink down out of the way. At Sydney University lengths of chain dip down into the water from the rear corners of the towing carriage. Instead of measuring carriage speed, the water speed relative to the carriage may be measured by two special current meters mounted on the front corners of the towing carriage. The first run of the day is used to check calibrate the current meters. But this is not the end of the story. Repeated runs and the laws of chance combine to set up a persistent surging oscillation wherein the whole body of water in the tank moves towards one end and then back towards the other end. For the Sydney University tank the surge velocity is around 3.3 metres per second and the period of the complete cycle is around 30 seconds. It is extremely difficult to damp this oscillation involving a mass of 500 tonnes of water and velocities measured in millimetres per second. Moreover, the major effect on measured ship model drag is not that due to the water velocity, but rather that due to the water slope. Like most other things, ships and models tend to run downhill, and as many ships would not have enough engine power to climb a water slope of 1 in 1000, a slope of 1 in 10000 in a ship model tank will lead to serious errors. There is no good answer to this problem. The surging can be monitored by a sensitive float at one end of the tank or by watching the drift of a ping pong ball floating at the middle of the tank. It shows up on the drag record as a rising or falling value instead of a constant value for drag. The Sydney University tank can be connected, at one end, through a 10 inch valve to another system. If the latter is not in use, and it is convenient to balance the water levels, opening the valve provides some damping for the surging. However tank operators must learn to live with the problem, and when it becomes too bad, to take an early lunch break.

The measurement of drag is rather difficult in a short tank. The desired signal, representing the drag of the model at a steady speed, is available as a short rectangular pulse. Typically this would be of ten seconds duration. Mixed with it, however, is a high level of noise. Here the term "noise" is used to denote undesired signals in any form; it is not restricted to audible signals. The noise in the drag signal comes from the interaction of the towing carriage vibration and irregular motion with the drag dynamometer and the model. At the Sydney University tank it is not unusual to have a signal to noise ratio as bad as one to one. If this were faithfully recorded the result would be a strip of paper mostly covered by a large blot of ink. Most of the noise must be stopped by some sort of filter. If a pulse of information having rectangular form and 10 seconds duration is to be reasonably recorded, the recording system should have a frequency responce from zero to 1 hertz or thereabouts. A peak in the noise spectrum comes from the surging of the towing carriage against the ropes at 2 hertz. Therefore a filter is required which will pass signals up to 1 hertz, but will severely attenuate signals at 2 hertz. When this problem was first tackled, 20 years ago, the solution was not so easy as it is today. Even in 1976, a low pass filter with a sharp roll off at 1 hertz, say, and a slope of 24 decibels per octave, say, is a rather sophisticated piece of electronic hardware, particullary if the filter time constant can be varied over a wide range. In 1956 the filter consisted of a buffer spring connecting the model to the dynamometer and a dashpot to damp the movement of the mechanically coupled recording pen. A little later a servo-operated dynamometer was used. The basic instrument had been designed in Germany around 1908, and was fitted with certain electronic and other devices by the present author. The modified instrument was described in a paper published by the Institute of Instrumentation and Control, Australia. The most significant feature was that the servo-system acted as a low pass filter and a rheostat controlling the servo-motor speed enabled the filter time constant to be varied. After using this for several years, a lighter and simpler balance was built which substituted an electrical output for the mechanical coupling to the recording pen. A regular Honeywell 10 millivolt recorder was used, this being a type developed for industial pyrometry. In between these two units an electrical filter could inserted. This trend continued and only the present system will be described in detail. But in doing so, some basic concepts must be clearly presented.

In small ship model tanks the drag dynamometer is usually a simple spring balance. That is to say the extension of the control spring is taken as a measure of the model drag. The dynamometer nearly always has, built into it, a means for calibrating the spring by the application of a calibrated dead weight load. The extension of the spring is picked up, magnified and suitably displayed. In the simplest case this may be done by mechanical coupling to a pointer or a recording pen, but more often an electrical displacement transducer is used so that the output is a D.C. voltage level linearly related to the extension of the spring and hence to drag force. In this case the display is a suitable recording voltmeter. In the Sydney University tank a Hewlett-Packard 7DCDT250 displacement transducer is used, which, through a home made filter, feeds the Honeywell, 10 inch strip chart, quarter second recorder. The transducer consists of a solid state inverter exciting a moving core differential transformer which feeds opposed rectifier systems so that for 6 volts input, the output varies linearly from -1.2 volt to +1.2 volt for movement of the core form -0.250 inch through centre to +0.250 inch, say from -6 mm. to +6 mm. displacement. Except for the sintered cylindrical magnetic core, the whole thing is encapsulated in a remarkable small package and can be used under water if necessary. The output impedence is high, so an integrated operational amplifier is used as a line amplifier with a voltage gain of 2, but adequate ability to charge the line and the holding condensers at the shore based recording station. The purpose of the latter is to hold the signal over small intervals of poor contact between the collector shoes and and the trolleywires. Since the line is short, less than 100 metres, it is operated at high impedance, and the input impendance of the active filter is made high by positive feedback. The line amplifier has a small amount of capacitive feedback so that it acts as a low pass filter and does not transmit any high frequency signals which could cause line reverberations. Nevertheless some thought must be given to the effect of picking up radio station 2JJ on the trolley wire system. Returning to the control spring: It is preloaded by calibrated weight in excess of the maximum expected drag. The transducer is at its mid position in these circumstances. A dummy run is made to record the zero, then the model is connected to the dynamometer and weights equal to the expected drag removed. When the test run is made, only the difference between the estimated and the actual drag is recorded. Naturally the strip chart recorder can be calibrated by adding or removing weights and it is important to realise that this calibration includes the whole system. While modern operational amplifiers are quite amazing to those who, like the author, struggled with D.C. amplifiers some thirty years ago, all electronics must be regarded with suspicion. Therefore professional electronic engineers build instant calibration and fail safe procedures into professional equipment. The preloading of the control spring keeps the system operating close to the zero reference condition, allows the recorder to be operated with an expanded display and without frequent change of range, and also tends to minimise some errors.

Now it might be appropriate to look even more closely at the control spring. It came out of the box of assorted springs purchased for the odd jobs. A set of springs had been ordered for the dynamometer and these were specially coiled, hardened and tempered. It was a mistake! The springs were obviously surface decarburised and, when tested, showed wide hysteresis loops. Cold coiled springs of piano wire, stretched to open the turns slightly, seem to be satisfactory. However the end fixings are very important in any measuring device where the overall dimension represents the force. Simple loops and hooks are quite unstable. Here the last turn is caught in a special clamp and tightly held in at least three places. The spring is hung vertically from an adjustable head and supports a cross-head below. This cross-head moves between suitable limit stops and is restrained by a system of ball bearing rollers to vertical movement without rotation. The carriers for the calibrated weights are attached and the moving magnetic core of the transducer rests on a plate attached to the side of the cross-head. The drag force, which is horizontal, must be turned around to the vertical direction. In spite of what one learns at school, the tension in a string passed around a pulley is not the same on both sides. A reinforced plastic aircraft control wire pulley has been spun on its own bearings against a tool post grinder so that it is simply cylindrical and concentric. A very thin ribbon of stretch resistant material is passed around the pulley to act as the "string". A tape of very thin, very straight, high grade spring steel would be ideal, but does not seem to be available in a size suitable for small models. A tape cut from shim brass stock, annealed and straightened, is used for models having particularly high drag. A thin tape of movie film based is reasonably satisfactory, but can take a permanent set and cause a readily detectable and rather unstable bias. Recently a length of milliner's thin nylon ribbon has been in use. It is hung under tension when not in use, and seems to be fairly satisfactory. Resistance to stretching is fairly important because, apart from the model reaching the end of its travel in the guide system, the slight change in geometry leads to a small but significant wandering of the zero drag setting on the recorder.

A rather different aspect of the control spring concerns the overall dynamics of the ship model test tank. Since the motion of even the best towing system involves some vibration, it is most undesirable to impose this extraneous motion on the model. Where the object is to measure model drag, and this involve skin friction, then it is likely that vibration could have a significant interfering effect on the boundary layer flow. Therefore, since the control spring is the connection between the model and the carriage, it is desirable to use as low a spring constant as may be practical. Another reason for the low spring constant is the need to achieve the optimum ratio between the response to steady state model drag and the response to irregularities in the towing carriage motion. By assuming such typical values as speed = 1 m. s^{-1}, mass of model = 10 kg. plus 20% for virtual mass, drag given by R.E. Froude's circle coefficient = 1.0, towing carriage surging amplitude = 2 mm. at 2 hertz, and a measuring run of 20 m., it can be established by a quite simple analysis that the softer the control spring is, the better. However, in order to interpret the drag record, it is necessary to include at least six and desirably ten complete cycles of oscillation of the model against the control spring within the steady speed run. A simple analysis based on the figures suggested yields the good advice that the spring constant should be the model drag divided by 0.025 metre. Naturally one does not change control springs for every speed in a series of test runs on one model, but, within reason, this advice is honoured in the Sydney University tank. It might be pointed out that the longer the tank, the softer the optimum control spring, and the more tolerant the overall system is to irregularities in towing carriage motion. Another fairly obvious point is that a very stiff control spring may be used provided a buffer spring of suitable stiffness is placed in series with the towline to the model. Again, in line with the philosopy that towing carriage irregular motions should not be impressed on the model, no damping is introduced and incidental damping kept to a minimum. Model drag tends to follow a square law or higher with respect to velocity, and this is more than sufficient to damp the oscillation which must result from starting the carriage and model from rest. This oscillation can be reduced by clamping the model during acceleration but cannot be entirely eliminated.

While discussing oscillations and other forms of noise in the system, it would be as well to consider the linearity of the system. The filter can be very effective in preventing the evidence of these oscillations from reaching the chart in the drag recorder. However, if the system is non-linear in any way, then a rectified component of the noise may add to, or subtract from the signal to give a false result. If the drag balance tips the limit stops, for example, the recorded result will be low although the record will show no indication of the impact. However a more insidious cause of error is an input of the form:

$$e_i = E_s + E_N \text{ Cos wt}$$

with a system response like:

$$e_o = e_i + k\, e_i^2$$

so that the output before filtering is:

$$e_o = E_s + k\, E_s^2 + \tfrac{1}{2} k\, E_N^2 + (1 + 2\, k\, E_s) E_N \text{ Cos wt} + \tfrac{1}{2} k\, E_N^2 \text{ Cos 2 wt.}$$

Filtering removes the oscillatory fourth and fifth terms. The first term is the desired response, and with the second, can be covered by the calibration procedure. But the third therm, $\tfrac{1}{2} k\, E_N^2$, is an error for which there is no obvious way for making a correction. Roughly speaking, for $E_N = E_s$, a signal to noise ratio of one, which is not so very unlikely, and linearity 1% of full scale deflection, the error is of the order of 1% of E_s. It is therefore important to ensure that the system is linear, but it is apparent that the necessary degree of linearity can be achieved with a little care. The linear range of the transducer is -6 mm. to +6 mm. and the normal procedure is to keep the cross-head in the centre position. The noise level is seldom greater than -2 mm. to +2 mm. The transducer still gives a sensible result from -12 mm. to +12 mm. but the extra range is not considered usable. After 12 mm. the limit stops are engaged. Within the 6 mm. range the linearity is better than ½% of full scale deflection. It has been found in practice quite easy to check the drag dynamometer visually and ensure that the cross-head remains within the linear range, while an occasional excursion outside the range will not be disastrous. The range of the electronic equipment is several times the maximum output voltage of the transducer, so no loss of linearity occurs in the filter due to overloading the operational amplifiers. A high degree of feedback makes the amplifiers, and the filter generally, quite linear.

A guide system for the model usually provides restraint in yaw, sway, and against the control spring, partial restraint in surge. Incidentally, it is quite unrealistic to use only a towline unless the test relates specifically to a towed vessel. Few hull forms are directionally stable when towed on a long line and this fact is not related in any obvious way to the course keeping ability of a ship when self propelled. The model guide system at the Sydney University tank can, if necessary, completely support a non-buoyant mode. The system consists of two miniature sub-carriages riding on longitudinal rails which are continuously rotating round bars. This eliminates static friction and reduces sliding friction to a very small value which is directly proportional to the longitudinal velocity the sub-carriages. The rails are rotated by a small electric motor. The connection to the model is usually made by dropping vertically a length of 17 mm. aluminium tube through a set of roller guides attached to each sub-carriage, and down into the model. The forward tube drops over a ball mounted in the model while a fork at the bottom of the after tube engages a longitudinal bar in the model. The towline from the drag dyamometer is fastened to the forward sub-carriage while a rigid tow bar connects the two sub-carriages together. Due to the telescopic nature of the tubular struts the model is free to heave and pitch as well as to roll. The whole guide rig can be yawed and the sub-carriage can be fitted with lateral force transducers. This is required, of course, for yacht model tests.

A serious disadvantage of this rig is that the sub-carriages are necessarily heavy and tend to run down hill as the towing carriage pitches. The pitching is due to imperfect levelling of the rails. The top surface varies up to 0.4 mm. above and below the mean level. If each sub-carriage weighs 2.5 kg., and the front wheel drop 0.2 mm. in a wheelbase of 2 m., the force involved is 0.005 newton. The drag measuring system has a resolution of 0.005 newton, roughly speaking, so that the pitching effect is tolerable. When a heavy model is fully supported by the rig, the variations registered on the chart are, naturally, very much worse. In the case of the yacht model test rig, the model is buoyant, but the lateral force dynamometers and the dry batteries which power them, at least double the weight of the sub-carriages. For runs in the normal speed range, the filter smooths out these variations to some extent so the drag record is readable, and the advantages of the guide system far outweigh the disadvantages. It should be realised that the variations in rail height are not cumulative and the measuring error is only that due to interpreting a chart which is a little confused by "noise". In the case of yacht model tests the drag dynamometer zero reading is obtained at the same carriage speed as the test run merely by running with the model uncoupled from the guide system. Where models are fully supported, the zero is the mean obtained from a very slow run forward and a run backward at the same speed. Such runs are made at speeds less than 0.1 metre per second. To prevent windage on the rigs causing errors, a perforated metal wind shield is used to reduce the air velocity over the guide system and dynamometer. Some judgment must be exercised as to whether or not air velocity over the model should be reduced, and this is controlled by the clearance height of the wind shield over the water. Windage affects trim and wetted surface of planing models and a Lambrecht velometer is used to check the relative air speed about such hulls.

The filter is the delight of an electronic technicians heart. It is electronic because electronic components can be purchased at quite small cost and no great skill is required to connect such components into quite complicated circuits. With switches it is possible to vary the characteristics of a filter over a wide range. To do the same thing mechanically would be enormously costly, requiring hundreds of man-hours of highly skilled instrument making and tool making effort. The idea has been, therefore, to start with a simple force transducer attached to the towing carriage, and use electronic signal conditioning before the shore based drag recorder. This provides maximum flexibility because only a small dynamometer and a model guide system need be unclamped and removed in order to set up the carriage for another job. It was a simple matter to build new filters as the state of the art advanced from paper condensers and thermionic valves to polycarbonate condensers and integrated micro-circuit operational amplifiers. (As a rough definition, an operational amplifier will amplify a small change in D.C. voltage level 20000 to 200000 times. The resolution at input depends on internal noise level and type, but will be better than 10 microvolts and possibly nearer to 1 microvolt. The amplification factor and linearity are rather uncertain in solid state electronic devices, but operational amplifiers are used with a high degree of feedback, so that amplification is, in this case, no greater than four. The result is a quite stable amplification factor and nearly perfect linearity. The frequency response of the basic amplifier does not usually extend much beyond the 10 kilohertz mark. Zero drift is always a source of irritation, but, in modern equipment, amazingly small and slow. In working terms, it is likely to be 1% of the recorder chart range per hour, or less.) The first electrical filter consisted of a resistor, an electrolytic condenser and a torch battery to polarise the latter. A passive parallel tee filter using canned paper condensers was built to stop the noise peak at 2 hertz. Various second order active filters were built using discrete transistors potted in blocks of brass surrounded by ploystyrene foam for temperature stability. Various fourth order active filters were tried but the present filter is third order and a good approximation to an ideal averaging filter with a variable time constant. It uses TAA811 integrated operational amplifiers, each of which is in a metal can about the size of a stack of three one-cent coins.

The idea of an integrator as an averaging device was presented to the author many times by well meaning colleagues. However, when tried in practice, the device is found to be quite temperamental, and even in principle, hard to handle. Zero levels, cut in and cut out timing, the tendency to reach the overload condition, the measurement of the integrator output at cut out time and before there was any drift, all presented too much difficulty for the device to compete with a continuous filter system. The approximate averaging filter continuously presents the average over the previous "T" seconds where "T" can be varied from around 0.5 second to 40 seconds by a single control. The output is fed to the strip chart recorder, and although there is some residual oscillation, the final average taken by eye is better than the resolution of the rest of the system. The continuous record presents a lot more information than the final output of an integrator and this allows the validity of the test run to be more reliably assessed, particularly when surges (seiches) build up in the tank. The mathematics of the averaging filter will not be reproduced here. It is sufficient to say that the response to a rectangular pulse of information, such as the output from the drag dynamometer switched in for, typically, 10 seconds, is a nearly straight ramp up to the final value, after which the output remains constant until the end of the information pulse. The duration of the ramp is "T" seconds, say 5 seconds in this case. The important point is that after "T" seconds the output of the approximate average filter is very close to its final value, say within ½% of the excursion, and remains within this tolerance. Depending on the fine tuning of the filter, there may be a slight overshoot. Compared with a number of elementary filters in cascade, the excess of settling time over averaging time is very much less. Five integrated operational amplifiers are used to generate the desired transfer function in a manner which permits convenient variation of the time constant, and reduces the rather heavy demand on the stock of capacitors. Otherwise the job can be done with only one operational amplifier. At present the system is patched up on a home made electronic analogue computer, but it is proposed to build it as a permanent unit. The response of the filter is easily checked by suddenly switching a small voltage offset into the filter and watching the recorder. The value of "T" is set to about half of the duration of the steady speed run so that most of the 12.2 metres of timed run is represented by a more or less level trace on the recorder chart.

The Honeywell recorder is rather fussy about the impedance of the circuits feeding it and about the noise level. It is a servo-operated potentiometer and the chopper type amplifier operating at 50 hertz can be easily paralysed by noise, and particularly by the mains frequency and its harmonies. Since the range of the recorder is 0 to 10 millivolts a considerable attenuation of the output of the filter is usually required. The input terminals of the recorder are bridged by a 200 ohm resistor and a 111000 ohm Cambridge decade resistance box is inserted in the connection from the filter. This arrangement attenuates the noise with the signal, provides a low enough impedance at the recorder to avoid electrostatic pick up of the mains frequency power or its hamonics, and avoids a capacitive impedance which would tend to destabilise the servo loop in the recorder.

The other feature of the measuring system worth mentioning is the automatic sequence control for the instruments. The time lost to waiting for the tank to settle after a test run is such that a good average performance is four good measurements of drag per hour. For serious work, a clear waiting time of five minutes is indicated by past experience. Of course, during setting up trials, runs are much more frequent. At such rates of working the operator cannot afford to miss a run by forgetting to set one of many switches correctly. To this end a series of track switches and relays has been installed which automatically connects the drag balance to the filter at the start of the steady speed run, thus avoiding charging the filter with the heavy transient signals developed during the acceleration of the model, starts the recorder chart drive motor, resets the electronic digital timers, stops the chart after the run, avoids recording on the return run and so on. The circuits are fairly basic and there is little point in describing them in detail. The system works very well and undoubtedly avoids the frustration of many lost test runs.

The Ocean Waves in a Tank

What are the wild waves saying ....?

Joseph Edwards Carpenter.

Modern seakeeping basins with elaborate wave making machinery are beyond the resources of people who are limited to "small" tanks and beyond the scope of this paper. The Sydney University tank is fitted at one end with a bottom hinge flap driven by a crank and connecting rod mechanism and backed by a parabolic beach of sheet metal. This beach absorbs the waves generated behind the flap, and, at the expense of efficiency, avoids having to tune the space behind the flap or cope with unfavourable resonances and wide variations in load. The waves travelling down the tank are absorbed by a similar beach at the other end. The drive is a four kilowatt Ward-Leonard set and a worm reduction gear box. Since crest velocity depends on wavelength and frequency, even slight variations in speed lead to longer waves overtaking shorter waves and utter confusion. For this reason the speed of the wave making machine must be precisely controlled, and is, in fact, kept in step with a reference generated by a ball and disk integrator obtained from a gunnery computer. This strange improvisation works well enough but otherwise has little to recommend it. With such a wave making machine, models can be run in head and following regular seas.

In some tanks, models are tested in irregular seas having standardised statistical properties matching records of ocean waves obtained by weather ships. No attempt has been made to use this technique at Sydney University. Oblique and beam seas are out of the question in a narrow tank.

Models must be properly ballasted for seakeeping tests and to this end the moment of inertia in pitching is measured in a rocking frame operated as a compound pendulum. When it is applicable, the metacentric height is checked by doing an inclining experiment and the moment of inertia in roll checked by timing the rolling period.

For tests in waves a "free to surge" rig should be used. Such a rig was built to suit models of motor boats around one metre long which tend to be quite heavy. A crosshead of minimum mass connects a vertical rectangular tube to a horizontal rectangular rail clamped to the towing carriage. The crosshead moves freely along the rail on ball bearing rollers and the tube moves freely through the crosshead, but all angular and swaying motions are prevented. The model is attached to the bottom of the tube by a ball bearing hinge which allows freedom in pitch. By locating the hinge at the design centre of gravity, and using the vertical tube as ballast, even placing ballast in a tray at the top of the tube, it is fairly easy to obtain the appropriate moment of inertia in pitch and the design static trim. The mass in surge is, unfortunately, too large by the mass of the crosshead. Potentiometers are used as transducers to pick up the pitch, heave and surge. A wave probe attached to the carriage picks up wave height and, with the impulses from the master pendulum, measures the wave encounter frequency. The outputs are fed to a multiple galvanometer photographic recorder. The towing pull is provided by a line passing over a pulley to a stack of calibrated weights, which also add to the mass in surge. The pull is adjusted by successive trials, but inevitably the crosshead will drift along the rail, and this must be recorded and used as a correction on towing carriage speed.

The accuracy is poor compared with still water tests. A cine-camera must be used to complete the record if sea-kindliness is to be assessed.

If tests on a free to surge rig show that surging is not significant, then a regular drag dynamometer may be used. This is much more convenient and accurate, so that the tank operator is always tempted to use it. However, in some conditions, surging is much greater than most people, including naval architects, expect. Therefore caution is adivsed and the point should be checked.

When making test runs in waves the width of the tank is rather important for the model motions generate waves which travel in all directions at a speed determined by encounter frequency. If these secondary waves strike the model after reflection from the tank walls, then the tests are, to some extent, invalid. If the model is stationary, then it is not unlikely that a resonant system of standing waves may be formed. While this system of secondary waves sloshing back and forth across the channel, can be quite spectacular, it is also quite unrealistic. Wave absorbers along the tank walls may help, but they will also interfere with the main wave system. To minimise the secondary wave energy in the tank, the wave maker is started just before the test run and the model accelerated in still water. With a little practice, the amount of interaction between waves and model before the useful part of the test run is quite small. The wider the tank and the higher the model speed, the more thinly this secondary wave energy is spread. As the model speed, v, and the wave encounter frequency, f, are increased in head seas, there is a changeover point when $vf/g = 1/(4\pi)$. Here secondary wave energy travels at the same speed as the model with quite marked effects on damping in pitch and heave. Above this, secondary wave energy is left behind. With such insight and a little care, useful tests may be run.

It is quite feasible to use very small, electrically self-propelled models to obtain some idea of seakindliness. These models are decked over and carry a simplified superstructure. The towing carriage becomes merely a detached speed reference and a platform carrying the power source. No thought of measuring power or thrust is entertained, for this does not, in any way, appear to be meaningful at the Reynolds Numbers involved. One operator is detailed to handle a fish pole from which flexible power and control wires drop vertically and yet loosely down into the model. Another operator controls steering and power while a third may use a cine-camera. At Sydney University a model less than half a metre long was run in this way. By following a zig-zag course down the tank this model could be subjected to seas on the bow and quarter as well as following seas. The results were little better than qualitative, but it was generally agreed that the exercise was well worth the small cost involved. This sort of test often shows up unsuitable placement of deck equipment, ventilators, deck openings and deckhouse doors, as well as insufficient free board and above water line buoyancey at various stations, and also the effect of bulwarks with insufficient clearing port area. With regard to the latter, some test on a model, representing a vessel which had lost power, showed that insufficient clearing port area was a factor in the loss of that vessel at sea. The mechanism of foundering was combined heavy rolling and pitching with a heading of 45 degrees to wind and sea. The weather bow scooped up water from the oncoming waves and this water was transferred by the rolling motion to the lee quarter. Eventually so much water was pressing down on the lee side that, over a period equivalent to three minutes for the ship, the model gradually overturned. When the bulwarks were removed the model could not be overturned, even when wave height was increased to an unrealistic extent. This finding was in line with reports from overseas research establishments, and confirms the view that ships are seldom lost by excessive rolling alone.

A particular interest at Sydney University has been the performance of 12 metre sailing yachts. In only a slight head sea, these craft can suffer an increase in drag to more than double the still water drag. The time allowed by the syndicates sponsoring the new yachts was inadequate for developmental work and the designers seemed forced to rely on still water test procedures, which, in this author's view, put too much emphasis on low wetted surface, full lines at bow and stern and a long hull at the expense of sail area. While the high drag increment only occurs when the wave encounter frequency matches the natural periods in heave and pitch, the dimensions and form of these yachts and the seas in which they sail match up in a most frustrating fashion. The damping on yacht hulls is very high and one cannot measure the natural periods by starting a free oscillation. The models were forcibly oscillated in heave or pitch in the slotted working section of a flume, while the relative amplitude and phase of forcing function and model motion were measured and recorded. The magnification factor was not startling, as would be expected from the high damping. The drag increment depends more on the phase. The forcing frequency at which a phase lag of 90 degrees occurred was noted as the natural frequency of the model. When the model was run in the tank against head seas the peak drag increment occurred at this value of wave encounter frequency. This work never progressed beyond the spare time efforts of the author but tended to support the old fashioned ideas of a long fine entrance with a deep forebody, centre of buoyancy kept forward, shallow but broad after body with centroid of water plane area kept aft, and a fairly gently diminishing curve of areas to retain fully attached flow at the stern, even when motions due to waves are superimposed on the forward motion. It was suspected that a long keel with the lower edge continuously sweeping downward towards the stern and carrying a full depth rudder at the after end provided advantages by way of steadiness in a seaway and monoeuvrability which more than compensates for the extra wetted surface involved. A fairly big rudder on such a yacht, balanced for two or three degrees of weather helm, can handle variations in the centre of effort of the rig and course keeping in a seaway with far less induced drag penalty than the small separate rudder which usually goes with a cut down keel. Unfortunately the author has not found time to devise and run a systematic series of test to check these ideas in a more objective manner.

Ship Generated Waves

The wild waves whist, -

Shakespeare's Ariel.

While storm generated waves race across the ocean, a quiter train of waves is generated by the ship itself, as it moves through the water. In a deep ocean these waves are dispersive, that is to say crest velocity depends on wavelength, and, in this case, energy travels at half the crest velocity. These features lead to the formation of the rather complicated, characteristic and quite fascinating pattern of waves about a ship. As a ship leaves port, a roughly triangular wave field, which grows continuously, trails behind it. The wave field lengthens at half the speed of the ship. The growth in energy content of the wave field can be related to the velocity of the ship times that component of drag attributable to the wavemaking. Naturally there is as much interest in measuring drag components as overall drag. The reason the latter is usually measured, and corrected for Reynolds' Number effects, is the difficulty of measuring the components separately and estimating the various interactions. In fact it is even difficult to think logically about components, when there are obviously highly significant interactions.

Apart from reducing wave making resistance as a step towards a lower fuel bill, there is a more direct interest in the desire to run passenger ferries somewhat faster than at present on Sydney Harbour. One of the limitations is the damage to moored craft, marine structures and the foreshores by wave action. Hydrofoil craft and air cushion vehicles do not seem to be the economic answer. Multi-hull craft seem to offer some advantages and a study of this kind has been set as a final year student project at Sydney University.

The author has maintained an interest in the work on measuring wave pattern energy flux which is going on at many tanks around the world. He has tried out most of the procedures himself, at one time or another, being assisted by Dr. L.J. Doctors or Dr. W.K. Soh of the University of New South Wales. So far none of the procedures have appeared entirely suitable for routine work, but it is becoming increasingly obvious that a simple routine method is needed which permits a wave record to be obtained during ordinary ship model resistance tests without any additional tank time being involved. The author considers that it may be better to take some short cuts at the expense of accuracy to obtain rough but reliable data. That is to say the method must not depend on tricky calibration procedures, elaborate equipment to be set up or special connections to large computers. To this end the author is using a float to follow the wave contour at a fixed station against one wall of the tank where the process of reflection doubles the amplitude. The float is a ping pong ball swung on a 450 millimetre arm from the spindle of a high grade instrument style potentiometer. The dynamics of the ping pong ball as a float will undoubtedly lead to errors, but at first glance these appear to be both tolerable and the least of several alternative evils. Reflections from the opposite wall of the tank are prevented by wave absorbers of a type being developed for the job. Floating pads of quite open fibrous material bonded with plastic extend outward 1 metre from the opposite wall for most of the length of the tank. The action of these pads must be gradual, otherwise the change in impedance will cause reflections. They rely on the passage of the waves, obliquely, through the pads to the wall, and back again through the pads, to attenuate the waves to a level approaching the resolution of the float gauge. Tests with improvised absorbers are encouraging, and a reasonable looking wave record has been obtained from a mathematical model. The interpretation of the wave record is not straightforward for it represents waves of different wave lengths carrying away energy at different speeds. The procedure is best considered in several steps.

First a control box is specified. This is fixed relative to the model, includes the tank wall, and is bounded by an arbitrary transverse line well astern of the model. The other boundaries are the course of the model and an arbitrary transverse line ahead of the model and of the wave pattern. The object is to calculate the rate at which wave energy crosses the boundaries of this control box, and since this is only half the wave field for a symmetrical model, to double the answer. For the present purpose a mathematical fiction is maintained in which a wave of half the measured amplitude passed through the tank wall, and the passage of reflected waves across the course is ignored. Second, the transverse waves, whose energy is passing downstream through the back of the box, are identified towards the end of the record. The energy flow rate is calculated and these waves are subtracted from the wave record to leave a record which starts from still water and appears to return to still water, rather than suffer an abrupt truncation. The function subtracted matches the wave record at the end, and is reduced, going towards the beginning, as if it were modulated by a versine curve. By suitably choosing the parameters, this artifice does not leave traces to be picked up by subsequent processing. Third, the wavelength of the transverse waves being fairly accurately known from the model speed, the front of the box is located at an exact multiple, N, of these wavelengths from the back of the box. The back of the box, is, of course, at the end of the wave record, disregarding the packet of waves from the acceleration phase. The residual wave record is then subjected to Fourier analysis for subdivision into N, N + 1, N + 2, ... 5N wavelengths. Fourth, the various wavelength components are separated, their velocities and direction computed, and the energy flow rates through the tank wall calculated. The total energy flow is found and this divided by the model speed to give the wave pattern drag of the model.

All this is usually done by turning the wave record into digital form and feeding the result to a large digital computer. A minimum of 200 offsets are needed, and as a manual task this is rather tedious. The sampling process can lead to computational problems if frequency components higher than the sampling rate are present. These may be in the original record or present in the digitised version as a result of small sampling errors. When the higher frequency components beat with the rate of sampling, spurious low frequency components are produced. Variations in the computational procedure are being studied by the author with a view to minimising these effects. Even the use of analogue processing at the tank side is being considered, and with the present rate of development of electronic computing devices, what is presently possible may become economically attractive.

Yacht Model Test in Still Water

A wet sheet and a flowing sea,
A wind that follows fast
And fills the white and rustling sail
And bends the gallant mast.

Allan Cunningham.

The yacht model tests done at Sydney University followed almost exactly the pattern set by the late Kenneth S.M. Davidson of Stevens Institute, Hoboken, New Jersey. The Australian naval architect had been using the tank at Stevens and wished to continue that work in Sydney. The first series of tests even used very similar instruments to those devised by Professor Davidson. The procedure he worked out was simple and effective, depending on some elementary graph drawing and arithmetic, which allowed the towing tank operator to choose just those combinations of speed, heel angle and side force which represented the full size yacht working to windward. The model was carved form solid wood, hollowed out and ballasted to achieve reasonable stability. It was not necessary to match the heeling stiffness of the yacht for this was done by arithmetic. This concession meant that the model was much easier and cheaper to build, and was much stronger than if the scaled heeling stiffness requirement had been met. The sails of a heeled yacht apply a downward force component, a side force component, a heeling moment, a pitching moment and a yawing moment as well as a driving force component which must equal drag. Davidson's procedure took account of all these. After setting the heeling angle and the forward speed, the appropriate side force, downward force and pitching moment were determined and applied. The heeling moment, leeway angle and yawing moment were found by trial runs, applied and measured. The model was free in heave and pitch. Finally the drag was measured. This carefully worked out procedure succeeded in getting three forces, three moments, three angular displacements, one vertical displacement, speed and drag all in balance with the minimum number of brial runs. The point is best appreciated by asking how many tests would be required to map a twelve dimensional space and how long would it take? The feasibility of the task depends on rejecting all unlikely combinations of the variables.

While Davidson's scheme is still followed in broad principle, some improvements have been made. The original test rig has been replaced by a more modern equipment which makes some adjustments automatically, avoids the need for others, and improves accuracy. Some indications of the nature of this rig were given earlier when discussing the drag dynamometer and model guide system, so it is only necessary to add a few comments. Each of the two lateral force dynamometers consists of a moving platform hung below a sub-carriage on four spring steel flexure strips, and a Hewlett Packard differential transformer which measures the deflection under load. This transducer is similar to the one on the drag dynamometer and delivers a D.C. voltage proportional to displacement and, therefore, to lateral force. The model is attached by a tubular strut sliding vertically through ball bearing roller guides attached to the moving platform. Since the latter has a parallel motion, the length of the strut does not matter. The model is, of course, attached by two struts to two lateral dynamometers and sub-carriages, so two lateral forces are measured. The after lateral force is displayed on a meter and the sum of the lateral forces is formed electronically and displayed on another meter. The yawing moment and C.L.R. can be determined from these readings. The heel angle is set by dropping the after strut through a squirrel cage clamped to the model. The bars of the cage and electrical contacts on the side of the strut form electrical control circuits which activate a motorised deck weight to balance the heeling moment. The displacement of the deck weight is a measure of this moment. With such a system a quite unstable model can be used and if the operator forgets this when disengaging the model he may have a salvage job on his hands. The leeway angle is set to generate the required side force by yawing the whole model guide rig and this means that the force component normal to heading and the force component in line with heading are measured instead of side force and drag. This change has interesting results. It makes the accuracy of the work less dependent on side force measurement and the force in line with heading decreases with increasing lateral force if the yacht functions as a reasonable efficient hydrofoil.

On the computational side the use of relatively slowly varying coefficients was developed to describe the effect of side force and heel angle on drag and the relation between side force, heel angle and forward speed. The former was based on the elementary form of the Lanchester Prandtl theory of lift induced drag and the latter was based on simple wall sided ship stability theory. Because these were, indeed, slowly varying, values determined over the useful ranges as a 3 x 3 matrix in each case, were sufficient to allow reasonably accurate and reliable parabolic cross interpolations to be made in an automatic digital computer.

The interpretations of these results depended on fitting to the yacht a standardised set of sails and predicting the best speed made good to windward as a function of true wind speed. Davidson's procedures allow this to be done quite satisfactorily using a slide rule, but today it is usual to feed the results to an automatic digital computer or to use a programmable desk machine.

Model

> Believe me, my young friend, there is nothing - absolutely nothing - half so much worth doing as simply messing about in boats.
>
> Kenneth Grahame.

Simply messing around is not good enough in this context. Models represent about half the expense of running tests in a small tank. They must meet a tight specification and it would be inappropriate to close this discussion without some reference to them. Unfortunately Sydney University cannot boast of any achievement in this matter other than the skill displayed by the staff in the pattern ship. There is no computer controlled model cutting machine, only a marking off table, templates and hand tools. Model making for tank tests is an exacting business. The easiest way to make a satisfactory model is to carve it from solid timber. To secure a well seasoned block, it is laid up by gluing planks together with a generous amount of epoxy adhesive. Models have been brought to the tank which have been glued together with casein and similar glues. They have fallen apart in use and become a total loss. For $50 worth of glue, $500 worth of model builder's time and $200 worth of clear timber has been lost, as well as the value of tank time. There is no way such a model can be repaired. To save the expense of solid timber, models are often built out of plywood. More often than not this is a failure. To be successful, every frame (not just half or a third of them,) which is to be found in the proposed ship, must be faithfully built in the model. Good results do not come from buckled sheets of plywood. For surface finish, old fashioned spar varnish is still the best. The model must be liberally coated inside and out. The worst finish is automotive "duco". It invariably cracks and lets the water into the timber. The surface of the model must be rubbed down using fine "wet and dry" abrasive paper backed by a fairly hard pad. Burnishing is pointless and generally leads to a wavy surface. The hull should be finished within 0.2 mm. of the lines plan, fair to the battern and smooth to the touch. If it is worth testing, it will have cost nearly $1000.

Fibre-glass (glass reinforced plastic) models are very useful, but are not originals. They are usually cast in a mould formed off a wooden original. Some foamed plastics can be substituted for wood, but require surface coating, and it is difficult to control this coating to achieve the final accuracy required in small models. The experience at Sydney University with such models has been very disappointing, and some of the models brought in for test could be fairly described as "dreadful".

For teaching and research, rather unusual models may be required. These vary from a triangular sheet of galvanised iron to complex mathematical forms. Visitors should not be surprised at what they see. Often it is more important to demonstrate the vices of one hull form than the virtues of another.

Rating Current Meters

Water, water, every where.
Nor any drop to drink.

Samuel Taylor Coleridge.

A large island amid the southern oceans, Australia has only limited supplied of fresh water. Conservation and careful management is of great national concern. The measurement and mapping of the water resources in this state is the continuing task of the hydrology section of the Water Resources Commission. Since November, 1954, the officers of the Commission have been bringing current meters to Sydney University for rating. Before that time the meters had been rated at Centennial Park, but vandalism became a problem, and compared with the rudimentary equipment which could be mounted there, the facilities at the univeristy promised far greater efficiency and accuracy.

Actually hydrologists do not require the ultimate in accuracy, and the rate of working in the tank is high to the point that a little casual time and motion study showed a profit. To save the driver descending from his control box to reach the gear box, a pneumatic remote gear change system was installed. The increase in the number of meters rated per day has covered the cost many times. Also, feeding sixteen test points into a computer which found the line of best fit and printed a rating table for field use, was an obvious step as computer services became available. This technique smooths out variations due to surges developing in the tank. These variations are unlikely to be large, nor are they systematic, so that the final error due to surges is probably around 0.003 metres per second. Current meters start to register around 0.03 metres per second.

The typical rating team consists of two officers of the Commission and three members of the University staff. The latter include a driver, a mechanical technician and the senior lecturer in charge, who is also the electrician. The last named might not be continuously present at the tank, but usually finds that his services are required to devise means for dealing with new types of current meter and to diagnose any problems which develop. The other four men are kept fairly busy. The results are processed by the officers of the Commission who handle all the paperwork. This teamwork is very effective and the Commission is recognised as a current meter rating authority.

The typical current meter is not unlike some types of marine "log". It consists of a fan (propeller) which is turned by the relative motion of the water and operates electrical contacts. These contacts operate counters or audible signals in field use. A specified number of counts is timed with a stop watch and the water velocity found from the rating table. In the rating tank each current meter is connected to a 1.5 volt bettery and a miniature relay. This operates a 50 volt circuit which jogs a pen on a seven pen chronograph. It is usual to run three current meters spaced across the tank. This chronograph, partly home made and partly based on a Both pen recorder, unwinds a 100 mm. wide paper chart at any selected speed from 1 mm. per second to 250 mm. per second. The two outer pens are connected to the master pendulum which provides one impulse per second, or may be connected through a gating device which allows every tenth impulse to reach the the pen solenoids. The next two pens are connected to a micro switch which engages cams on the track set 6.1 metres (20 feet) apart. Comparison of the blips on the three current meter traces with the time and distance blips provides the information needed for rating. The use of only a 1.5 volt dry battery, instead of the laboratory 50 volt 2 kilowatt supply, is rather important. The low voltage almost eliminates electrolysis and with the miniature relay, avoids damage to current meter contacts.

The object of setting out this procedure in some detail is to make some points about measurement technique in general. The author built a system which provided a direct digital readout for current meter rating when the early vacuum tube digital counter devices first came on the market. While the author himself used it, the system worked well, but it dealt with only one meter at a time and did not use the tank to best advantage at that. The system was utterly confused by a bit of dirt on a current meter contact. Worse, it did not produce hard copy. Thus, there was no automatic documentation. The old fashioned method, using a chronograph, makes the best use of tank time, provides the maximum amount of information on the serviceability of the meters, automatically provides a calibration document provided the paper chart is annotated so that clock rate and meter identity are recorded manually, and is never confused by dirt on a contact. The disadvantage is the work back at the office measuring and digitising the analogue record. If the system is to be made automatic, possibly the best method would be the use of a 100 character per second, 5 or 8 hole paper tape punch. If a suitable clock controlled the punching rate so that it became the time reference, then such a punch could be used as a chronograph. The tape could be read by eye at the tank side, (as many computer operators are in the habit of doing,) and with a suitable programme, is a computer compatible carrier of information. Some quite cunning and some fairly high power electronic control circuits would be needed, but, except for the cost barrier, this equipment is available. Of course it would be necessary to select a computer equipped with a tape reader. Such a system has most of the advantages of on-line interactive computer processing at a fraction of the cost.

In the mean time the staff at the tank faced some recording problems. These were summed up in two words: "Pen blockage". The pens on the original Both recorder would block sufficiently often to be a problem. It is far from economic to have the tank and three men idle while a fourth struggles for an hour to feed a blocked pen. To say "an hour" is not to exaggerate. The current model Both recorders use heat sensitive paper and heated styli, which made good sense to the physician who owns a portable electrocardiograph. Pressure sensitive and light sensitive paper are other possibilities. However the cost is high considering the quantity used, the supply position is not good, and the shelf life of light sensitive paper is short. Simple writing paper and fountain pen ink is the obvious answer for the writing speeds involved. Therefore a new top deck was designed and built for the Both recorder, with a view to meeting the following requirements: (a) Spare pen circuits to be available. The extra pens on the time and distance marker functions are instantly available if a current meter pen misbehaves. (b) Spare pens to be available. The pens are straight lengths of 1mm. stainless steel tube tipped with 0.3 mm. bore tube and weighted. They are syphon fed through 0.6 mm. bore, very flexible, surgical grade, transparent plastic tubing. The pens literally drop into plade. A pen can be changed in 30 seconds. (c) Each pen must have its own independent ink reservoir, adjustable for height to control the ink flow. (d) Each reservoir must be sealed except for a vent hole to which air pressure can be applied. The usual technique is for the operator to use his own lungs and cheeks. He is supplied with a length of flexible tube tipped with a finely tappered brass nipple which may be pressed into a vent hole. A beaker of antiseptic solution is also provided. (e) All pens must be easily lifted, the tubes air-locked, and the writing tips left immersed in a beaker of clean water at the end of the shift. So far the recorder has worked very well indeed, so well that the only complaint is the nuisance value of many metres of chart draped over furniture while the ink dries out. The chart is re-rolled for easy storage. The cost of modifying the recorder in the University workshops is unlikely to be revealed, but was undoubtedly quite high. If anyone knows where a commercial version, built to the same specification, may be purchased, then the author would be grateful for that information.

Like any other velocity measuring instrument used in the ship model tank, current meters are subject to tank blockage and free surface effects. From time to time officers of the Water Resources Commission have done experiments to check on these. If a current meter is to be used on a staff, it is mounted on a similar staff for calibration and run at a fairly typical depth below the surface. If it is to be run on a steel wire rope, with a tail fin, and a lead ballast weight below, then so is it calibrated. To give some idea of the free surface effect, an ordinary 8 mm. Prandtl type pitot static tube set 100 mm. below the water surface, with the stem vertical and breaking the surface, will read low at 1.5 metres per second by something like 3 percent of the velocity. The fan of a current meter is mounted well forward of the staff in order to reduce this effect.

The Future

If you can dream - and not make dreams your master;
If you can think - and not make thoughts your aim;

Rudyard Kipling.

The level of activity in the Sydney University tank has risen and fallen in sympathy with many changes that have occured in the last two decades, within and without the university. The transfer of the Department of Mechanical Engineering from the old campus to Darlington has had a more depressing effect than was anticipated, and this brings up the fact that the size of the department is such that the author is the only member of the academic staff continuously active in towing tank work. He was quite heavily involved with the new building, keeping in touch with the architects and, in particular, planning the two largest and most heavily serviced laboratories. Also the relative isolation of the tank has been felt, as supervision is no longer just a matter of running down two flights of stairs.

Without the university, the events of the latter part of 1976 do not suggest a happy future for the shipbuilding industry in Australia. This may reduce the number of students interested in naval architecture and this, in turn, may reduce the enthusiasm which is the main driving force in keeping the tank operating effectively. However the changing pattern in the industry may lead to new attitudes in both management and labour. A determined and constructive approach to find new solutions to old problems may lead to a more vigorous though smaller industry, attracting able students to naval architecture, and, of more interest to Sydney University, to the package of undergraduate courses offered in the broad field of transportation engineering. One thing is certain: Australia will continue to need an effective and efficient transport system and men, to plan it and to run it, who understand the workings of all the basic forms of passenger and cargo carrier. Optimistically, then, (if not too realistically,) the author hopes to see the tank playing a small part in the research and development effort required by a new social, economic and industrial pattern which seems to be slowly evolving.

In another paper the author put forward the view that there is no middle course when it comes to establishing ship model tanks. A university or college can run a tank as a part time effort, but once a permanent staff is assigned with sufficient range of expertise to form a viable unit, then the annual wages bill would fairly demand quite a large tank. This is just a matter of marginal economics. The best return is only obtained when capital, labour and other factors of production are in optimum proportions. In the present circumstances it seems unlikely that another tank, large or small, would be built in Australia.

So looking into the next decade the author expects to see the tank kept in operation for teaching, undergraduate research projects, some general research projects, and some regular chores like rating current meters. He hopes that naval architects will continue to bring some of their problems to the university. As a professional school, the Department of Mechanical Engineering must keep in touch with industry, and this is one of the more constructive ways of doing so.

The author has had more than a passing interest in the scaling procedures to be followed when predicting full size performance from model tests. This interest continues, and although no "break through" is expected with regard to the number one problem on any tank man's list, at least someone at Sydney Unviersity will know something about the matter. To this end experiments with wake survey techniques and wave pattern measurement will continue. Some studies which have been set for undergraduate projects in 1977 refer to the need to produce, for Sydney Harbour, ferries which can travel fairly fast without producing disturbances in the water likely to cause damage to moored craft and waterside structures. During 1976, two students from the University of New South Wales have been working on undergraduate projects. One is the actual measurement of the pressure distribution under a planing hull. (Everyone knows, but who has carefully measured it?) The other is a study of the effect of Froude number on the side force developed by a yawed plate, representing, say, a ship turning. Both experiments are inteded to check theoretical calculations.

The author, like most academics, spends just a little time dreaming. What would he like to see as a national ship hydrodynamics laboratory in Australia? Well there is no doubt that very bright people are one of the necessary factors of production. The bright people will undoubtedly work better in bright offices with bright young ladies who can not only file papers away, but know how retrive them as required. Next a few small computers and, if possible, a medium to large one. Then a man who knows how to keep computers and their peripheral equipment in first class order. Put these factors together and a lot of worthwhile research may be done, with or without a tank and the specialist staff required to service it. If the tank is to be, then let it be designed for maximum flexibility. If the designer knows what the tank will be doing, then it will not be research, but routine testing. Let there be a lot of well serviced clear floor space, some basic equipment and some money in the bank to buy whatever is needed, when it becomes known what the need is. Surely nothing is more wasteful than equipment grants which must be spent before the first day of September!

If the author is permitted to dream a little longer he will see hazy pictures of a large rectangular tank, say 40 metres by 100 metres by 10 metres deep, surmounted by a moving bridge along which the towing carriage runs. Like the workshop crane, the motion of the bridge varies the X-co-ordinate while the towing carriage varies the Y-co-ordinate. Using high quality servo-motors the position of the carriage may be computer controlled for straight towing or complex manoeuvres. With hydraulically controlled wave makers on two sides, random and complex seas may be generated. But, by the time all the details have been worked out, it may well be that the need is for a different facility, perhaps a 200 metre long tank built into a vacuum chamber, and dedicated to the study of propeller cavitation coupled with hull vibration.

But sometimes the dreams are bad. What is the picture then? A laboratory designed by a committee of experts. Money lavished on expensive equipment which takes up all the floor space. A team of research workers dedicated to the task of trying to find some line of research which will at least appear to justify some of the nice equipment available to them.

Perhaps it is time to awaken!

In Appreciation

Let us now praise famous men -
Men of little showing -
For their work continueth,
And their work continueth,
Broad and deep continueth,
Greater than their knowing!

Rudyard Kipling.

As this has been, in many ways, a history of the Sydney University Tank, it is appropriate to record a note of appreciation of the Professors and Heads of the Department of Mechanical Engineering, G.G. McDonald, P.T. Fink, D.W. George and presently R.I. Tanner who have directed, encouraged and tolerated the author. Also he would remember his predecessor, now retired, Mr. Keith Mann Hart. Much of the equipment came off the drawing board of Mr. Les Sarvas and was translated into fact by Mr. Alan Scott. Many friends in industry have helped to equip the tank and many tank superintendents around the world have let the author see their tanks in action. To all these, many thanks.