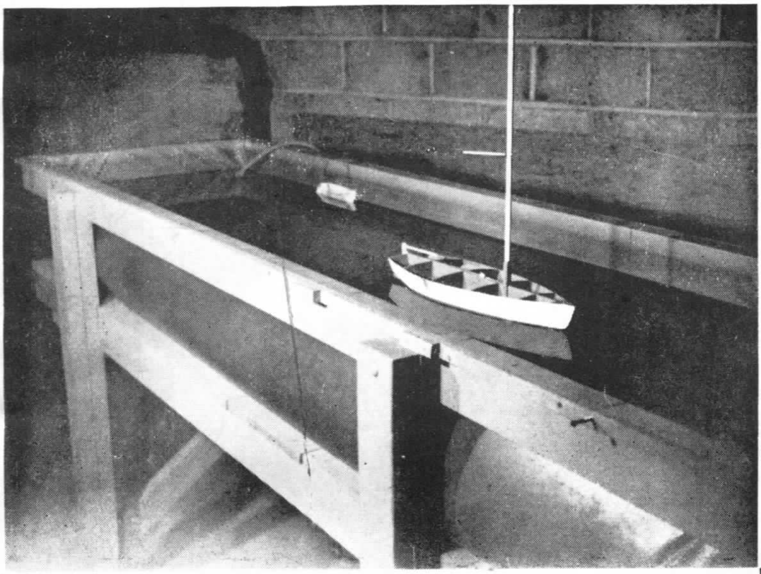
TUNNEL AND TANK

A.Y.R.S. PUBLICATION No. 30



THE BRUCE TANK

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(Founded June, 1955)

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April, 1960.

EDITORIAL

This is the 30th A.Y.R.S. publication and marks the end of five years of work which, in most people's opinions, have been very fruitful. It is indeed interesting to examine just what has been accomplished.

CATAMARANS. Five years ago, the only really good catamarans were those in Hawaii and the *Shearwater I*, in England. The rest tended to be of the deep chine type which have stability and, when conditions are just right, quite a high top speed but on the whole are marked by a performance far worse than the thoroughbred dinghies. The *Yvonne* 20 was just coming along at that time with her shallow chine and there were some others.

Now, there are large numbers of elegant round bilge and shallow chined catamarans of many different designs which, in nearly all cases, are faster on all courses and in all wind speeds than the best dinghies of comparable length. From the vast number of letters which have been sent in to the A.Y.R.S. from all over the world (which now fill two tea chests), it is quite obvious that all the people who have designed catamarans have read our publications and, in many cases, have used the information which we have accumulated.

TRIMARANS. Five years ago, practically the only trimarans made of marine plywood were being designed by Victor Tchetchet and these were fast craft like *Egg Nog* and *Flamingo*.

Now, Victor Tchetchet's latest trimaran looks a very speedy craft while Arthur Piver and Louis Macouillard have produced an independent type which is most elegant and satisfactory. In the rest of the world, the trimaran appears to have been neglected, despite its proven advantages but this position will be quickly remedied in the near future, as a result directly of the A.Y.R.S. We would have liked to have shown a design by Arthur Piver as an example of the best of the configuration but this is not now available. It is hoped that the *Padang* (" long knife " in Malay) will show the main features of the configuration and how 4 berths and 6 feet of headroom can be fitted into the 25 feet of such a craft.

THE POLYNESIAN CRAFT. Five years ago, there was only the *Malibu Outrigger*. Since then, the *Islander* has been shown. With the float system and connectives of *Padang* and the excellent hull shapes of the craft shown in CATAMARANS 1959, this type of craft may be expected to come into its own. In my opinion, the type is only suitable for inshore racing where it should be the fastest multihull possible. A cruising version with ballasted keel was, however, outlined in OUTRIGGERS 1959.

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THE MICRONESIAN CRAFT. This configuration is, to me, the most delightful and romantic of all the multihulled craft. A. E. Bierberg, Skovbrynet 23, Lyngby, Denmark is still its greatest protagonist. Though possibly a little slower than the Polynesian type, it should still be faster than all the others. Five years ago, Mr. Bierberg was converting Canadian canoes of moulded plywood to Micronesian craft but now, he has made a boat of this type to the conventional Micronesian pattern but in plywood. Some interest in the configuration is at last beginning to form.

HYDROFOIL CRAFT. Five years ago, only the Baker craft had really been made to sail on foils, though others had been " up " such as Gilruth's and Professor Davidson's. This situation remains virtually unchanged today, though our experiments with *Jehu* and Professor Martin Royle's *Avocet*, using hydrofoil stabilisers have made some advance.

SAIL RIGS. During these five years, we have collected many examples of experimental rigs which have been tried out and conjectured many others. Nothing very precise has been proved of any of them and none have really been shown to be an improvement on the conventional sloop. However, the semi-elliptical sails should, in fact, be really good and would be well worth trying out.

YACHT CONSTRUCTION. This has had some consideration in MODERN BOATBUILDING and FIBREGLASS, two very useful publications. Little which is completely new has emerged but systems of " overdevelopment " of plywood surfaces are becoming more used nowadays.

EXPERIMENTAL PROCEDURES. In these last five years, many people have complained that we have done no active technical research. This is so, of course, but we have been slowly accumulating methods of research during this time which are suitable for ou members and, if we can get our Yacht Wind Tunnel going and also a test tank or even accurate towing tests in a canal, we will be able to produce figures for our more technical members to work with. In general, out technical members seem to be the most impatient but, with our limited facilities both in knowledge and cash, we must progress very slowly towards our objectives in this field. Five years is indeed a short time to wait to get enough backing for technical work.

THE NEXT FIVE YEARS.

The nature of the work which will be done in the next five years can surely be forecast with some accuracy.

Catamarans. It should be perfectly easy during the next five years for anyone to build a catamaran capable of the greatest possible speed. By making the craft really light, of good shape and with great beam and sail area, it can be made to win races if well sailed. The rule makers may therefore want to fix a minimum to hull weight and a maximum to beam and sail area. Or, they may find a formula to allow craft with these variables to race together.

Trimarans and Polynesian Outriggers. It is to be hoped that even this year, someone will have the initiative to combine a *Cougar*, *Thai*, *Tiger*, *Wildcat* or some such hull with one or two *Padang*-like floats and connectives to produce an elegant and speedy craft. From all the information available, this should not produce a craft with a higher top speed than the equivalent catamaran but the speed in light, and moderate winds should be much greater. In any case, sail area, weight and cost should be much less.

Micronesian Canoe. Owing to the lack of interest in this type, development will be slow. Someone may (or may not) get as far as building one of moulded plywood which is really light and with an outrigger to match. We hope so.

Hydrofoil Craft. During the next five years, now that Martin Ryle has shown how the configuration can be used, we will certainly see many more experiments with hydrofoils. A small horizontal hydrofoil of about half a square foot of area placed on the tip of each of his foils and the rudder would quite possibly convert his *Avocet* into a lifting hydrofoil craft without any other modifications.

Sail Rigs. Within the next five years, someone will undoubtedly use a semi-elliptical sail with no twist on a boat either as a " square-sail," " fore dipping lug " or as a " mast-aft " rig. There is every reason to believe that he will obtain increased sail forces and ratios.

Experimental Instruments. We will undoubtedly have got some interesting information from our Yacht Wind Tunnel and possibly also from hull testing. Both the construction of wind tunnels of this type and size and their handling are complex and the mathematical corrections for " blockage " and " wall " effects may not be easy. Our technical advisors have advised us that our tunnel may not be a fully scientific instrument, though it can be made to be nearly so. In that case, let us build the Yacht Wind Tunnel with the idea that it will give good *comparative* information on the relative values of different sails for the same boat or class of boat and thus render a service to our yacht racing brethren. If we can also derive yacht sail " coefficients " from it, we will then be more than satisfied.

THE FUTURE OF THE A.Y.R.S.

When the A.Y.R.S. began, the first thing to do was to collect members who were interested in the development of yachting from any point of view. At that time, as indeed at present, it was impossible to develop a project for which our members could work together. As a result, the A.Y.R.S. developed by its publications, correlating the various work by individuals and helping still other individuals do still more work. The " break-through " in the multihull field came just at the right time for us and this form of yachting was seized upon for development as it was so ideally suited to our organisation (or lack of one).

Now that we have a large enough membership to include people of all kinds of interests and spheres of knowledge, it should be possible to lay on some real experimental work with some pretensions to scientific procedure by constructing our Yacht Wind Tunnel and Test Tank. Both of these pieces of apparatus are suited to our membership because individual experiments can be done by people more or less on their own.

It has been pointed out by Dr. C. N. Davies that any Yacht Wind Tunnel or Test Tank which we are likely to put up at Woodacres could not be expected to produce results which would be fully scientific in the usual sense of the word owing to the lack of enough expert knowledge in myself and most people who would be using them. Dr. Davies feels that the best results could only be obtained if the Yacht Wind Tunnel were to be taken under the wing of a University.

A Yacht Wind Tunnel suitable for a University would cost something in the region of £5,000 and graduate students, carrying out research work for higher degrees, would be available to operate it and, possibly, to assist A.Y.R.S. members who used it. The Yacht Wind Tunnel we are thinking of would cost less than £1,000 and the running expenses would be negligible. It is therefore felt by other members that we should go ahead with our cheaper Yacht Wind Tunnel and see if fully scientific results will be achieved. It may be that enough people of superior scientific knowledge will be interested enough to come down and get figures from yacht sails from which a fully scientific analysis can be made. Even if this does not happen, the Yacht Wind Tunnel will at least be an instrument which should be capable of giving a service to individual yachtsmen by making a *comparative* examination of the sails of their boats so that they should be able to know if their sails are going to produce the greatest possible forces.

The Ultimate Fate of the A.Y.R.S. It has already been conjectured that at some time in the future, a COLLEGE OF YACHTING may be formed. This, surely, will then meet the wishes of those who want to have the Yacht Wind Tunnel and Test Tank under the control of fully qualified scientists as this " College " would presumably be attached to some University or other. Such a " College " could be visualized as set in the grounds of a large country house where members could stay and study. One of our well known yachting lecturers could be appointed as " Director " while doubtless, a " Librarian " could be found. If placed, for example, half way between London and the South Coast, one feels that it would be constantly consulted by yachtsmen about their various problems.

The idea of a COLLEGE OF YACHTING is very attractive but a Yacht Wind Tunnel which would be suitable for it, though not costing perhaps £5,000 would have to be much more expensive than the present concept at Woodacres. With the experience which we could get from a Wind Tunnel at Woodacres, costing about £1,000, we would know if such a COLLEGE OF YACHTING would be justified.

The Tempo of A.Y.R.S. Development. Several people have joined the A.Y.R.S. in the past with the idea that we would be laying on scientific research immediately and have been disappointed that this did not happen quickly. Some have dropped out though, when I have been able to get to know them and explain what is happening, they have kept up their membership. In short, it is just a matter of time. It takes time to collect members. It takes time to collect designs for the apparatus. It takes time to collect the people with knowledge who will help us. And, it is necessary for all the apparatus to be designed and tried out before fully scientific work can be laidon.

Dr. Davies is correct, of course, in wanting the apparatus under the control of fully qualified people as an ultimate thing and we are working to that end. But, in the meantime, it surely is the proper thing to do what we can with the resources at our command.

The A.Y.R.S. has been in existance only five years during which time the possession of a Yacht Wind Tunnel has been an objective (it was mentioned in publication No. 1). Now at last, we have several designs for a suitable tunnel and the facilities for erecting it. The minds of men move slowly, like the Mills of God, and, if we can have patience, we can lay on what is needed " exceeding sure."

THE BRITISH A.G.M.

Minutes of the A.G.M. held on the 2nd January, 1960, at 11.30 at the Cedars Hotel.

Dr. Davies (vice president) took the chair, and after introducing the officers to the members, the meeting was formally opened. The minutes of the previous A.G.M. were read. A proposition to adopt the minutes was proposed by Erick Manners, seconded by John Morwood, and carried.

Matters arising from the minutes of the 1958/9 *meeting.* Arrangements have been made with Capt. O. M. Watts Ltd. to produce the A.Y.R.S. burgee, details of prices etc. are to be published in our publications (see No. 29). It was agreed that the possibility of producing a tie should be pursued, the design adopted for the motif being the one that was voted as second choice when the burgee design was considered.

Election of officers. Mrs. Evans and Owen Dumpleton retired from the committee. The appointment of Mrs. Evans as Research Secretary was confirmed, and Owen Dumpleton was re-elected to the committee. John Morwood proposed that Mr. Gresham Cooke be elected to the committee. This was seconded by Tom Herbert and carried. Because of the possible application of inflatable wing techniques to sail design it was agreed that Mr. Neumark be appointed as our representative to co-ordinate research on inflatable wing techniques.

Financial Reports. This year the cost of publishing booklets has balanced income, and some of the deficit of previous years recovered. Financial policy would continue to be one of making the costs balance the income. John Morwood suggested that profits could be passed to the research fund to assist in financing the wind tunnel but it was felt that this might cause complications, and would require amendment to the Society's Constitution. At this point the administrative arrangements for the proposed wind tunnel were discussed, and it was agreed that the cost of building and running the tunnel made it necessary that the legal and financial aspects of the project be competently handled. It was resolved that a wind tunnel committee be appointed and plans prepared for the formation of a limited liability company to control its erection and operation. Mrs. Evans reported that the research fund has reached £143 with several firm offers of equipment either free or at reduced cost.

Policy for the coming year. To reduce the burden on the editor it was agreed that the number of publications should be reduced to four per year, each of them having an increased content. The main effort will be directed towards the building of the wind tunnel.

Wind tunnel and test tank projects. It was hoped to obtain permission to make use of the Royal Military Canal at Hythe for tank testing. The Essex members have not been able to make use of the facilities that we had available on Southend pier and Erick Manners is to inform the corporation that for the time being these facilities will not be required.

The proposed design for the wind tunnel was discussed at length. It was agreed that the working area of the tunnel must be capable of containing full size sails so that full size tests can be carried out on the dinghy classes sailed in the Olympic Games. It was felt that the design displayed at the Boat Show (which has been vetted by the Fairey Aviation company's wind tunnel experts) would be capable of producing consistent results and should be capable of producing the required wind speeds and velocity gradients in the working area.

Should it prove impossible to build this tunnel full size, it was agreed that cheaper types of tunnel should be considered provided it was technically possible to carry out accurate tests in all reasonable weather conditions.

The meeting closed at 2.45 p.m., votes of thanks were offered to Mrs. Morwood for manning the stand at the Show for long periods without help, to Norman Pearce for his illustrations in the booklets, to Mr. Gresham Cooke for the use of his house as a meeting place, and to Ruth Evans for her hard work as research Secretary.

THE A.Y.R.S. MEETING ON MARCH 12TH, 1960

The meeting took place at the private house of R. Gresham Cooke, M.P. Thirty-two people were present. After a 40 minute film of "Catamarans" made by Erick Manners, which was most enjoyable, the Yacht Wind Tunnel project was considered with Lord Brabazon in the chair.

Lord Brabazon, in his opening remarks, stressed the fact that the ordinary yachtsman was completely uninterested in such a project at the moment, but could become so if it were proved that a yacht wind tunnel was of value to him. Experience with the Yacht Research Council had shown that public subscriptions did not bring in any great amount of money for such work. Institutions who already had wind tunnels had been approached by him to see if they would do tests on sails but there had been no response. The trouble about any yacht research was that there was no money in it for anyone to be paid.

The project of erecting the cheapest possible satisfactory yacht wind tunnel at Woodacres was then examined. While it was felt that such a tunnel could have some uses for yachtsmen and it might be the only place in which a tunnel could be erected, it was pointed out that there were some objections : (1) it was too far away from most yachtsmen, and (2) no firm offers of help and advice had been gathered from technical people who could give advice on the working of the tunnel and their time in making precise studies.

The accuracy of the tunnel was then called into question. Some guessed at an accuracy of plus or minus 5% but Mr. R. J. Harrington Hudson stated that he had been able to find the centre of effort in a 3 foot tunnel to an accuracy of one tenth of an inch. If comparable results to Mr. Hudson's can be obtained, the tunnel will be a scientific instrument.

The meeting decided unanimously that a Yacht Wind Tunnel project was wanted but, for the present, Universities and Technical Colleges should be once again approached by letter either to the heads of their aerodynamic departments or in their journals to see if any of them would be prepared to build a full sized yacht wind tunnel on their premises. Lord Brabazon undertook to do this.

In case the Universities and Technical Colleges fail to show any interest in a yacht wind tunnel, we should now have a list of the members who would be prepared to come to Woodacres at weekends to help run the tunnel. A 4-berth caravan will be provided for accommodation and tents could be erected. Will any technical member who is willing to do this work please contact the Editor ? A certain number of non-technical members will also be required for cleaning, maintenance and generally acting under the orders of the technical in the taking of readings. It would also be a help if we could have the names of those people who would be keen to test their dinghies or catamarans in such a tunnel.

The thanks of the meeting were expressed to Lord Brabazon for coming along and to Mr. and Mrs. Gresham Cooke for so kindly and generously giving us their hospitality.

H. C. Adams, Owen Dumpleton and U. K. Gerry have, since this meeting, designed a yacht wind tunnel which they will make at quarter or fifth scale this summer (6-8 feet high).

MEET THE MEMBERS.

The A.Y.R.S. is such a scattered Society that meetings have been difficult to arrange. Even the A.G.M. in London has been only sparingly attended. In order to give the Society the feeling of fellowship in some way, therefore, it has been suggested that we have short accounts of the interests of various people. We start this in this publication with accounts of the Officials of the British Section with America represented by Victor Tchetchet and Arthur Piver. There is nothing subtle in this selection of people for the first accounts and, if the procedure is welcomed by members, it will be continued. The various secretaries will send in the accounts of their members who are actively engaged on interesting work and they will be published.

President :

Lord Brabazon of Tara. Yachting and other interests described in A.Y.R.S. No. 12. He is very keen on the A.Y.R.S. Yacht Wind Tunnel.

Vice-Presidents :

Uffa Fox. Contributions to yachting described in A.Y.R.S. No. 18.

C. N. Davies, is a physicist who has specialized in fluid mechanics. He has been canoeing and sailing for 35 years during which time he has owned boats ranging from racing kayaks, via a 25-ft naval whaler, which he converted himself and described in his book "New Boat for Old" (Faber), to his present yacht, a 16-ton gaff schooner.

In 1952 he started systematic experiments on paddling canoes and since then has designed and built a prototype a year with the object of learning about speed, stability and seaworthiness. He built the first glass fibre-polyester resin canoe in the country and the first round-bilge conic developed hull of plywood sheet.

In place of a testing tank he started an annual race round Mersea Island to obtain data on performance ; from this followed the present series of Long-Distance races held under the aegis of a technical committee, of which he is a member, of the British Canoe Union. He is the author of the handicapping formula and nomogram used in these races which attract large entries of the British canoeists and are playing an important role in bringing on potential candidates for the Olympic Games.

Dr. Davies is a member of the Royal Canoe Club, the Walton and Frinton Yacht Club and the Chelmsford Boating Club of which he is the Hon. Technical Adviser.

Erick J. Manners. The interests and personality here are mainly those of the engineer with commercial interests. Has designed and manufactured many boats, the *Catamanner* and *Minette* range being the best known ones.

1. Intense study in 1935 of the amount of compound curvature which flat sheets of plywood can take in order to build boats with this material of the best possible shape. Several of the *Catamanner* range are made thus, for example, 11-ft. *Car-Cat ;* 14-ft. *Racer* and 18-ft. *Luxury Catamanner*. Others are of fibreglass.

2. Intense study of remote control equipment, using transmissions which could be used to control more than one function at a time. This range of work was also manufactured in a large variety of types for all sorts of engines and remote regulation purposes.

3. Electronic alarm systems for water levels, oil pressures etc., Ships' telegraphs ranging from the traditional to push-button types have also been made.

4. Technical teacher lecturer in sailing, seamanship and boat-building technology.

5. Multihull pioneer in England. Has experimented with trimarans and hydrofoils as well as the catamaran sail and engine powered range with which his name is mostly linked.

Associated companies are : Twin Hulls Ltd., Cappadocia Works, 50a, Salisbury Avenue, Southend-on-Sea, Essex.

Thames Craft Manufacturing Co., (Established 1934), 93, Ridgeway, Westcliff-on-Sea, Essex.

President, American Section :

Walter Bloemhard. Yachting and other interests described in A.Y.R.S. No. 13.

Vice-President (New York) :

Victor Tchetchet. Built his first catamaran of two 18 ft. hewn very light hulls of kayak shape, called *Chelnok*, in Kiev, Russia, in 1908.

After graduation from Imperial Art School, went to Germany to continue his education, where he was a sailing, rowing and decathlonist. Was four times South-West champion in speed and figure skating in addition to rowing and sailing in regattas of Kiev Yacht Club with highest reward, name engraved on Golden Board.

During First Russian Olympic Games in Kiev, 1913, won 3 gold medals for sailing in a sloop built by him, *Storm*, skulling and decathlon.

Went to America after the Russian revolution and, in 1936 in collaboration with Professor Sartakoff, after trials with models of different configurations in a pond, started building a 25 foot catamaran. This craft was finished in 1944 but it was very heavy and slow.

In the fall of 1944, he started his first trimaran 22 ft. 6 in., and she was launched in the Spring of 1945. She was fast and manoeuvered well. Guest log of this boat included, among others, Boris Lauer Leonardi (editor of the *Rudder*), and his late wife Barbara, John Hays Hammond, the famous inventor, and Robert N. Bavier, author of several books, later secretary of the North American Yacht Racing Union and founder of *One of a Kind Regattas.*

Next year, 1946, on the suggestion of Boris Leonardi, 17 enthusiasts founded the International Multihull Boat Racing Association for which Victor designed 20, 22, 24 and 26 feet long trimarans.

At the Marblehead regatta that year (1946), he was first told that " since the disqualification of N. G. Herreshoff's catamaran *Amaryllis* in 1884 or 5, such freaks are not permitted to participate in racing competitions." However, Commodore Francis P. Munroe and the Corinthian Yacht Club allowed Victor to enter the Handicap Class, but the trimaran was overloaded with three husky people and the showing was poor, only once being second against 32 craft of all kinds, including decked canoes.

A few weeks later came the Manhasset Bay Y.C. Fall Series. To avoid possible rejection of the entry of a trimaran, Victor placed on the desk of the Chairman of the Race Committee clippings from the Boston newspapers showing that a " Catamaran " was officially racing at Marblehead Regatta, and, as the " precedent was established," the boat was accepted for the Handicap Class. She won the race.

In 1948, five trimarans from 16 to 22 feet long established an official Multihull Class for the first time in the history of racing on the Atlantic Coast and perhaps in the United States. To this fleet Bob Harris later added his *Naramatic* and still later, *Ocelot* (both described in A.Y.R.S. No. 10).

In 1950, Victor's first trimaran was destroyed by a gale so he built a 26 foot one called *Last Pal*, which won several races. In 1951, he built *Egg Nog*, a slightly modified version of the original Trimaran. In 1953, Francis X. Dealy borrowed *Last Pal*, which he renamed *Sheer Coincidence* and built a sistership *Flamingo*, described in A.Y.R.S. No. 16, of the best materials and with dacron (terylene) sails. This boat won several races.

In the First International Multihull Regatta of 1959, which was held in conjunction with friendly Bayside Yacht Club under the auspices of *Imbra*, Bob Harris *Tiger Cat* was the fastest as well as some other cats against the trimarans, which were old boats with old cotton and small sails, inferior to the modern full battened dacron sails of all the cats.

In trimaran group the winner was *Egg Nog I*, skippered by James L. Smith, (former crew to Olympic champion Eugene Vallett) with his able crew Jack Chapman.

Victor hopes that more boats will come to the Second International Multihull Regatta scheduled for August 5 and 6 of this year.

The *Imbra* has unique and impressive Trophies donated by L. Francis Herreshoff for Catamarans, publisher William Randolph

Hearst for all types of multihull yachts, famous aviator, owner of old Russian, R. A. F. French, and U.S.A. wigs, Capt. Boris. Boris V. Sergievsky for trimarans, Tom Varley Memorial and Victor Tchetchet Trophies for trimarans also.

In A.Y.R.S. No. 15 Catamaran Design it was stated that Victor's hull design owed something to the *Lear Cat*. It would be apparent from this account that this is not so and I must apologise for this error.

Arthur Piver. Born San Francisco Feb. 12, 1910.

Extensive sailing background, but all in heavy displacement types. Family owned 86′ schooner for 25 years, one of the entrants in 1925 San Francisco-Tahiti Race.

Was Air Force pilot in World War II. This had influence on my interest in light, strong construction. Loved beauty of sailing but for excitement was addicted to skiing and surf riding.

First interested in multihulls in 1953. Purchased Lear Cat kit and sailed her in 1953. I loved the speed and excitement of catamaran sailing, but decided the Lear Cat could be improved. This led to my first design, the 20′ *Pi-Cat*.

I decided that the reason people did not like *Pi-Cat* was unconventional appearance of twin hulls, so decided to design a sailing dinghy for speed plus public acceptance. Incidentally, I believe that my dinghy designs are fully equal to anything I may have accomplished in multi-hull field. *Nutshell* is the only dinghy I know which will plane close-hauled to windward (no extraneous hiking gear necessary). She can plane clear around a triangular course, except when actually tacking. Reasons for her performance include light weight and flat floor, which eliminates usual bow wave. This boat does not need to rise in the water to plane, as she is practically on top of the water to begin with.

The 10′ dinghy *Scooter* (1958) is a two-in-one boat. When sailed level, her bottom is long and narrow. When heeled by stronger wind, she becomes beamy and stable. 360-degree rotating goose neck (no stays) allows sail to flog down wind by any heading. Oh yes, the local sailors wouldn't ride in *Nutshell*, either. San Francisco Bay is considered too rough for dinghies.

After *Nutshell* came 18′ *Rocket*, first as a single outrigger. This conformation proved too unsteady for our gusty conditions, and she was made into a trimaran. A 20′ *Rocket* followed.

No one could be induced to build a *Rocket*, apparently due to the difficulties (more apparent than real) of constructing the round bottoms of strip planking or moulded ply.

This led to *Frolic*, with thanks to the 90-degree (Morwood) section. A 20′ version of this boat was developed (*Caper*) for persons who wanted larger capacity craft. Because we seemed to have solved immediate problems in these smaller boats, it seemed logical to go next to a cruising type, the 24′ trimaran *Nugget*.

In an attempt to conquer some problems (principally manoeuvrability) still existing in catamarans, the 17′ *Pi-Cat* was built in 1959. I believe she renders obsolete all catamarans which are not highly manoeuverable, which apparently includes all the ones I have seen (with the possible exception of *Freedom*, which is heavier in proportion than is *Pi-Cat*).

Am now (December, 1959) building 30′ ocean-racing trimaran *Mirage*.

Other boats built include 12′ *Junior Trimaran ;* a V-bottom foamed plastic version of *Nutshell* (sailing characteristics similar to round-bottom prototype).

Sidelines include Flap Propulsion (after A.Y.R.S. concept) ; tilt rig ; Mylar sails ; ribbed sail ; Sheet-release mechanism.

Research Secretary :

Ruth Evans, was born in East London, South Africa in 1920 and was brought up there and in the neighbourhood of Cape Town where Table Bay and the inland lake of Zeekoe Vlei fostered an inherited interest in sailing and in yacht and boat design. She had practical experience in a yacht builder's workshop and in canoe building as well as in drawing and design.

After her marriage, Mrs. Evans lived for some years in the Sudan where sailing was to be had in the winter months on the Blue Nile at Khartoum. Since returning to the United Kingdom, she has made models of several types of outrigger craft for the A.Y.R.S. She owns an Enterprise dinghy on the Thames.

Hon Secretary :

Tom Herbert. Age 34. I am a communications engineer in the engineering department of the Post Office. My first attempt at boat building was at the age of eight when a successful craft constructed from 40 gallon oil drums, odd lumber, and tastefully furnished with old car seats, was launched on the river Stort. For several years it carried us safely through many adventures until finally stolen and broken up by a rival gang of pirates. Later at school I was able to indulge in water sports for most of each school year. In the holidays too I spent most of my time either on or in the water. In fact, I seem, over the years, to have acquired a reputation for being mad about boats. Since childhood I have been interested in sailing ships, and particularly in the Polynesian and Micronesian outriggers and catamarans. I am deeply interested in yacht design and sailing techniques. In fact anything floatable and capable of being propelled on water arouses my interest. I suppose my reputation is well deserved.

THE EDITORIAL FUNCTION

The Editorial " We " is extinct nowadays. But, if any publication anywhere has more multiplicity of ideas coming into the Editorial office than the A.Y.R.S., I would like to know of it. Since the A.Y.R.S. began, vast numbers of letters have arrived daily till the total to date must be something like 6,000 to 10,000, and this does not include a simple request for a publication.

If therefore, a statement is made by me, as Editor, it usually has a background of the ideas of many people and is not simply my own. For instance, there are over 60 pages of letters from Arthur Piver which naturally range over the whole sphere of his interests in the trimaran and catamaran fields with a leavening of other subjects to do with boats as well. There is, perhaps, a similar amount of writings from Frederic A. Fenger on the shape of conventional boat hulls and the " Wishbone Rig " with the engineering of spars and staying as sidelines. But it is not so much the letters of just a few individuals which make up the Editorial background but the accumulation of the ideas of a great many people.

The Presentation. It has been very difficult for me adequately to present the new ideas which have appeared. Where the concept can be attributed to one person, this is done, of course, but when the idea has been presented partially by several different people, the term " I " is used, which is used to express my synthesis of the matter as EDITOR. In my opinion, the term " We " would look as if the responsibility for the judgment (which could be wrong) was not being properly taken up by the Editorship.

Examples. The right angled V section for catamaran and outrigger hulls was first suggested in A.Y.R.S. No. 15 and this section has been found useful by Arthur Piver for the bows of his craft. However, this section was frequently used for commercial sailing vessels and is the logical one to use for a chine boat once the importance of low wetted surface was proved by *Shearwater I.* It was as Editor that the sorting of the ideas produced the concept.

Similarly, the right angled triangle for outrigger float sections appears naturally when viewed from an abstract point of view as an improvement on the " square box " sections used by Arthur Piver and Louis Macouillard in some of their craft, which itself might have had an A.Y.R.S. origin.

The Personal Contacts. Quite frequently, people appear at my house with models or plans of boats which they hope to build. It is in discussions of these that very many old ideas are sorted over again and sometimes the germ of a new idea will appear.

In addition, there are people who have some aspect of yachting which they hope to see developed and advise on the technicalities. Owen Dumpleton who, incidentally, was the first A.Y.R.S. member, has advised about the technicalities of the Wind Tunnel and has most kindly hunted up a great deal of information on many subjects. Austin Farrar, is, of course, a fund of information on any aspect of yachting one cares to mention while, for specific problems, the advice of many eminent A.Y.R.S. members has only to be asked and it is given freely. Norman Naish, of Folkestone, though not a member, has been most helpful and many a problem of design and construction has been talked over with him before publication.

Summary. The Editorial function of the A.Y.R.S. is an accumulation of the ideas of very many people both by letters and personal contacts and their synthesis into formed concepts where this has not been done by individuals.

Editorial Activities. With this publication, 46,000 publications will have been printed and some 40,000 sold. Back numbers are kept reprinted, when the publishing fund runs to it but there has been little profit owing to this as it ties up money in unsold publications. Stands have been taken at the last four London Boat Shows, which have been costly but well worth it for their prestige value. This has resulted in quite a lot of work for a single-handed spare time hobby and it is hoped that I will be forgiven if some of my letters to members have not been as well expressed as they might have been and an occasional publication has been late.

Personal Viewpoint. As an individual, the whole point in the yachting studies I have done and the objectives I see for the A.Y.R.S. is to be able to design yachts for myself, which I can be sure are the best possible in theoretical and practical efficiency. Also, I want to be able not only to design but to build my own boat to this specification and to test both the hull and sail or sails in a test tank and wind tunnel to make sure that this has been accomplished. This is my personal bias for the record and, when it has been achieved, I shall be completely satisfied.

The Editorial policy at present is founded upon the belief that all professional yacht designers and builders should carry out the objectives set out in the preceding paragraph and that any amateur should have the advice and facilities available to him to do likewise.

PADANG (" Long knife "—Malay)

	Main Hull.	Float.
L.O.A.	25 ft. 0 ins.	18 ft. 0 ins.
L.W.L.	22 ft. 6 ins.	
Beam	4 ft. 0 ins.	3 ft. 0 ins.
Displacement	2240 lbs.	1680 lbs. (Immersed)
Beam O.A.	18 ft. 0 ins.	
Draught	1 ft. 6 ins.	4 ins.

Designer : John Morwood, for Norman Naish, Esq.

This design is included to show what may be the final trimaran configuration and also how 4 berths and 6 foot headroom can be got in the 25 feet of this type. A.Y.R.S. members will recognise its ancestry as the hull shape features are all those so well developed by Arthur Piver.

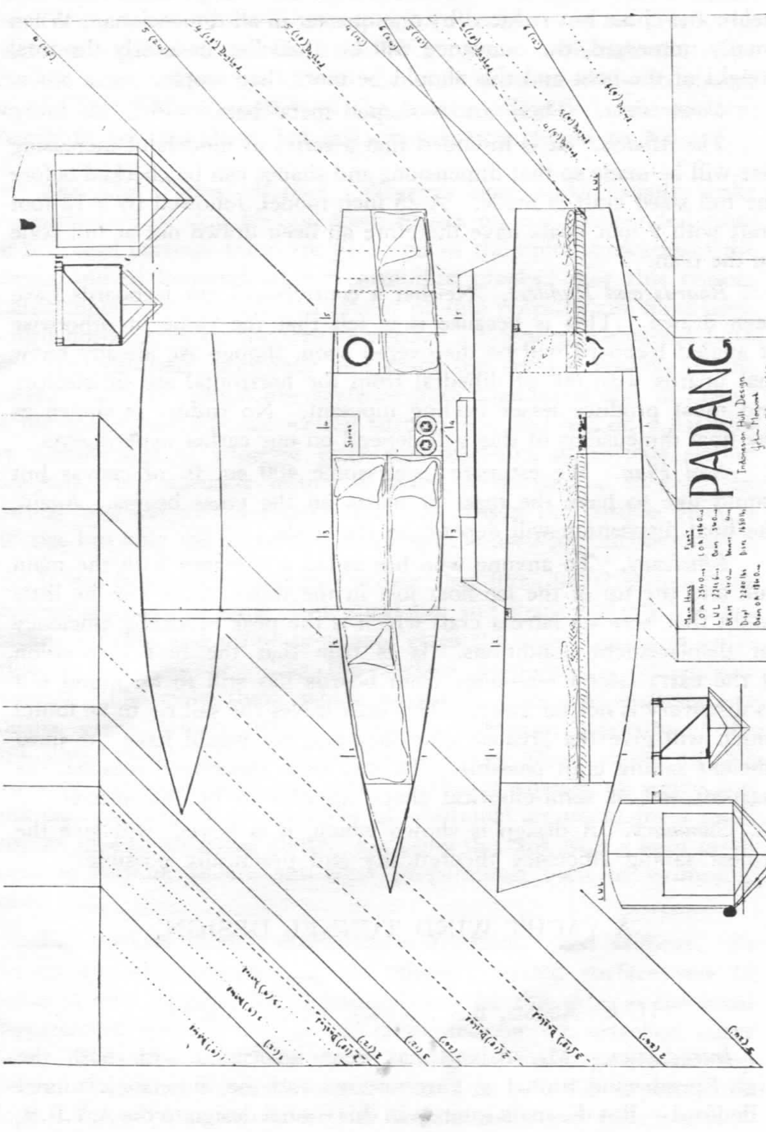
The Main Hull. This has the forward lines and sections of *Parang* and *Tamahine* which have been shown to go well. The after sections are flattened from a right angled V at the greatest section to a fairly well V'd transome. There is a lot of fullness aft which will take the weight of all the crew in the cockpit and, at the same time produce some " suck-down " at speed to keep the bow up, though it is not yet known if this is a good thing.

Norman Naish is confident that he can build this trimaran down to a weight of half a ton and at that weight, even with her crew, she would be high on her marks but in cruising trim, I have estimated the displacement at 1 ton. This difference of opinion is the cause for the greater V of the transom than perhaps is desirable.

Both Norman and Dr. Derek Musslewhite are making models to examine the water flows and accommodation plans.

Accommodation. The principle cabin has a double berth, galley and toilet, though this can be adapted for use in the after cabin while everyone is in the cockpit. Single bunks are placed in small cabins aft and forward, giving 4 berths in all.

The Cockpit. The coachroof only extends far enough aft to cover the double berth and the stove. Aft of this is the cockpit which can be covered by the sliding top which, in turn, has a smaller hatch so that only one person need be out to steer in bad weather. Six feet of headroom are present under the sliding top. A full width seat at the after end of the cockpit should be pleasant and, in fine


PADANG
Indonesian Hull Design
2nd February 1960

weather and when sailing, the crew can sit on the deck of the aft cabin, with the coachroof sides extended aft around them for security.

The Floats. These are of exactly the same shape as the main hull below the chine but reduced by one quarter in all dimensions. When totally immersed, the buoyancy will be 1680 lbs. or nearly the total weight of the boat and this should be more than ample.

Connectives. These are N-shaped metal bars.

The Models. It is intended that a series of models of increasing size will be made so that dimensions and shapes can be checked before the full sized craft is made. A 25 inch model, followed by a 12 foot craft with 9 foot floats have therefore all been drawn out at full scale on the plan.

Boards and Rudders. Neither a centreboard nor leeboards have been drawn. This is because it is felt that the value or otherwise of angled leeboard will be discovered soon, though we already know that boards with 60° of dihedral from the horizontal are satisfactory and must produce lesser heeling moment. No rudder is shown as the final dimensions of this will depend on our earlier experiments.

Sail Plan. We estimate using some 400 sq. ft. of canvas but would like to have the mast or masts on the cross beams. Again, the final disposition will depend on the trials.

Efficiency. To anyone who has sailed a trimaran with the main hull and the tip of the lee float just in the water, there can be little doubt that here we have a craft which is the peak of sailing efficiency for displacement conditions. It is true that the best disposition of the extra lateral resistance from boards has still to be found but its discovery is not far away. This only leaves the sail rig to be found which will give the greatest efficiency and we would have the most efficient sailing craft possible. To me, from theoretical reasons, the mast-aft sail of semi-elliptical shape appears to be the answer.

Summary. A design is shown which, it is hoped, will give the utmost sailing efficiency theoretically and practically possible.

A YACHT WIND TUNNEL DESIGN

by

H. C. ADAMS, B.SC., (ENG.), A.C.G.I., A.M.I.C.E.

Introduction. Mr. Adams has been associated with both the High Speed wind tunnel at Farnborough and the Supersonic tunnel at Bedford. But the main interest in this tunnel design to the A.Y.R.S. is the fact that Mr. Adams seems to have appreciated our problems to a nicety and one feels that he not only knows what he is talking about in aircraft wind tunnels but can also translate his knowledge to a Yacht Wind Tunnel, which needs a slightly different approach because of the low wind speeds etc.

Since the publication of No. 24 YACHT WIND TUNNELS in which a satisfactory yacht wind tunnel was described, there have been several criticisms and suggestions most of which dealt with the tunnel entrance. Mainly, these suggested greater clearance below the tunnel " bell mouth," which would have made the tunnel more difficult and expensive to build. By contrast, Mr. Adams' present design seems to go straight to the essential we need with a reduction of the complications and expenses of construction and running costs.
Mr. Adams criticism of the Yacht Wind Tunnel of No. 24.

Point 1. The surround " air smoother " would no doubt be effective against gust effects but cannot affect steady wind pressures significantly. For the wind speed envisaged here, steady external wind pressure must exert a large influence on tunnel velocities and open ends would, as pointed out, severely limit the times when the tunnel could be used.

The above comment is, of course, subject to the wind tunnel experts but, if cogent, implies a closed circuit tunnel. This could well be a closed building over the tunnel, the return circuit being formed by the space between the tunnel and the external walls. This has been used in the past and is probably cheaper than the conventional closed circuit. It requires considerably less power than an open tunnel, of course, friction losses only having to be made good.

Point 2. *Intake.* The bottom roll (of the " Bell mouth ") is, I think, unnecessary. An aircraft tunnel must have no transverse velocity gradient but here a vertical gradient is actually required (or implied by the suggestion of " fences "). Air flow over a (roughly) level sea is needed. Eliminating the bottom roll (and pit and fences) will produce this.

It is also practicable to use a reduced area at the intake, increasing in a gentle taper to the working section (5° is, I believe, the maximum divergence). This reduces the size of the bell mouth (an expensive item) and also (probably more important) the size of the surrounding building. The 10 foot radius intake roll appears large for the tunnel size and speed.

GENERAL LAYOUT

The illustration shows a suggested general arrangement and the resultant reduction in size. The economies are considerable. Airflow in the working section should be satisfactory but could be quickly and simply checked with a model.

"*Blockage Effects.*" I have assumed that you have investigated the effect of a model with a large transverse area e.g. a boat on a broad reach, on the tunnel characteristics and flow pattern. Aircraft models are normally tested at small angles to the tunnel centreline only and are of small cross-sectional area. I make the effective lateral area of a 12 foot dinghy at 90° to the tunnel axis to be about 20% of the tunnel area, with the sails tending to produce a flow at right angles to the tunnel flow. Mutual interference between sails and tunnel walls seems likely.

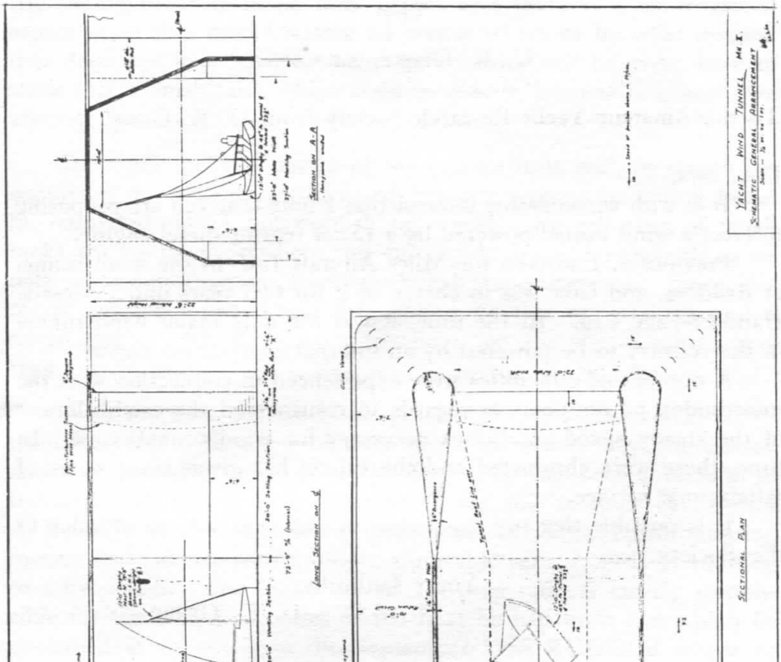
Mast Clearance. I agree that the masthead may be close to the tunnel roof (though there is a tip vertex here).

Cost. The additional cost of enclosing the tunnel may sound formidable at first sight, but I have done a preliminary exercise on this and it need not be so, I think.

Editor. Undoubtedly the tunnel suggested here by Mr. Adams is the cheapest possible, if used as an open tunnel. If erected firstly as such, a very large sheet of polythene could be placed outside the entrance to minimize the friction over the grass and the air flow is likely to be reasonable. However, an open tunnel would be of little use as one would have to wait for long periods till the natural wind settled down to a calm, and, as soon as our finances run to it, the tunnel should be enclosed in the manner suggested by Mr. Adams.

It must be confessted to A.Y.R.S. members that, though the tunnel described in publication No. 24 has been discussed with many people, no useful suggestions for any alternative tunnel or useful modifications of that tunnel have been received till this one by Mr. Adams. It is now obvious that we have here the cheapest possible tunnel (of the open kind) and also a closed circuit tunnel which would be excellent.

Having at last got something to deal with, we can now make a model and see if it will be satisfactory. But we still need all the help we can get from our aeronautical members both in criticism and advice.



YACHT WIND TUNNEL Mk X.
SCHEMATIC GENERAL ARRANGEMENT
SECTION ON A-A
LONG SECTION ON ℄
SECTIONAL PLAN
SECTION ON B-B

A YACHT WIND TUNNEL DESIGN

by

U. K. Gerry, A.F.R.Ae.S.

To the Amateur Yacht Research Society from U. K. Gerry.

Dear Sirs,

It is with considerable interest that I note that you are proposing to erect a wind tunnel powered by a Lister marine diesel engine.

Previously, I worked for Miles Aircraft Ltd. in the wind tunnel at Reading, and later was in charge of it for two years under Messrs. Handley-Page Ltd. At the time, it was the only major wind tunnel in the country to be powered by an internal combustion engine.

A number of difficulties were experienced in connection with the unorthodox power plant as regards to control and the establishment of the steady speed conditions necessary for wind tunnel work. In time, these were eliminated and the tunnel has given many years of satisfactory service.

It is possible that my experience in this field may be of value to the Society.

Yours faithfully,

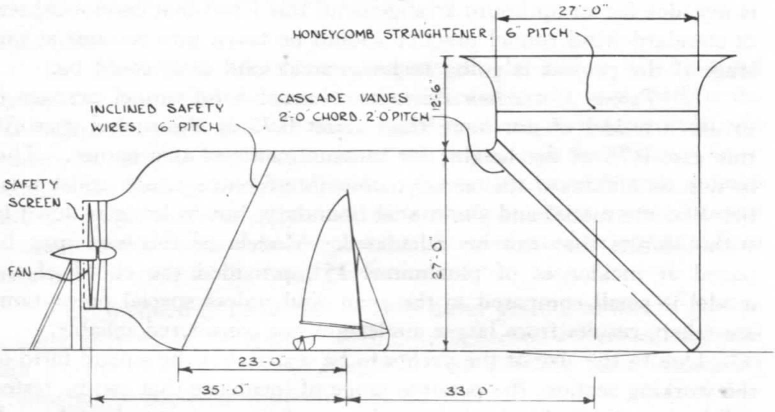
U. K. Gerry.

To John Morwood from Owen Dumpleton.

Dear John,

In a telephone conversation with Mr. Gerry, we discussed the difficulty in controlling the wind speed. The point is that as soon as you alter even one sheet in your rig or the attitude of a crew member, you will need a different engine speed to produce the original air speed. It would be difficult to do this automatically since the " air speed " for our purposes means the speed past the rig and, if you alter the sail trim you will normally also alter the blockage ratio, or ratio of the amount of area presented to the flow by the rig and hull to the full area of the tunnel. Therefore, you will alter the required quantity of air to simulate a given free sailing wind speed. There are thus two unknown laws viz., the relation between flow and fan speed for varying blockage (and hence pressure drop) and the relation between flow and simulated true wind speed.

Mr. Gerry is also concerned about our entry funnel and has references claiming that the required clearance between the lower



lip and the ground should equal the working diameter. This is clearly impractical so he suggests as an alternative, the provision of a cascaded angle to cock up the entry funnel through a right angle. (If the cascade blades were made adjustable, this would provide a very elegant method of velocity gradient control.)

Many modern diesel engines, especially " industrial " versions, are normally controlled via a governor and we should check that a good one is built in and is fully adjustable over the available speed range. It will be necessary to fit to the engine an electric or other remote actuator and a remote tachometer so that the engine can be controlled by the observer in the boat. We will also need anemometers on both walls of the working section and provision for moving the boat transversely to the air stream following each change of trim so that the " free air " velocities on both sides of the boat are equal (or follow some realistic law).

Best wishes,

Owen.

To Owen Dumpleton from U. K. Gerry.

Dear Mr. Dumpleton,

The horizontal entry of the form shown in the sketch may prove to be as insensitive to external winds and gusts as any simple structure can be.

I think that a practical wind tunnel for yachts could be built for an economic sum and I trust that, if you put this design before other aerodynamicists, you will not convey the impression that this is my idea for an optimum arrangement, but I feel that certain aspects of standard wind tunnel practice should be taken into account at this stage if the project is going to be as successful as it could be.

1. *Tunnel Correction Factors.* Normal wind tunnel practice is to use a model of not more than about 0.75 of the tunnel span (in this case 0.75 of the height) for measurements of this nature. This is not to eliminate the aerodynamic interference which must arise between the model and the tunnel boundary, but to bring it down to within limits that can be calculated. Models of this size may be tested at incidences of plus/minus 15°, provided the chord of the model is small compared to the span, and unless special precautions are taken, results from larger angles are not considered reliable.

Due to the size of the yachts to be tested and the square form of the working section, the possible range of incidence that can be tested will be very limited indeed if any degree of accuracy is to be achieved. Even then, the labour of calculating the tunnel correction factors necessary to obtain free stream forces, which will differ for each type and size of rig, will be considerable.

Even in the case of a small vessel the considerable length of the sail in proportion to the tunnel width must preclude any measurements beyond the incidence range of plus/minus 15°. There could be no question of accurate measurement of the thrust of the sails running before the wind.

2. *Determination of Zero Loads.* The cables connecting the vessel to the spring balances will have to be under tension in no wind conditions otherwise the configuration that the vessel takes up may be quite arbitrary. Thus, before testing commences, the vessel will have to be set at all angles to be tested and the zero loads measured. If a crew is to be aboard during the test, this means that they will have to be in their identical stations that they will assume during the test.

The cables will have to be set up horizontally and be maintained horizontal throughout the test, unless the tedious procedure of measuring the inclination for each reading is followed and the load components worked out.

I am sure that you will appreciate that wind tunnel engineers are just as practical in their own way as yachtsmen and that they would not bring such complications as tunnel correction factors into the picture if there was any way around them. I do hope that the A.Y.R.S. will consider looking into these and other problems of wind tunnel practice in this early stage, because difficulties arising later may be harder to correct.

Yours sincerely,
U. K. Gerry.

To John Morwood from Owen Dumpleton.

Dear John,

On the whole, Mr. Gerry is generally in favour of the wind tunnel but is worried about the mathematics of the various coefficients. He makes the point that the wind speed gradient varies from place to place according to the roughness of the water and the distance from land. The laws governing this do not seem to be very well defined and we think that the only reasonable thing to do is to test in zero gradient as the standard and regard the effects of wind velocity gradient as a modification to the basic performance.

I am inclined to think that we will never get the tunnel to give an answer that could be applied with confidence to a free sailing craft but the use of such a tunnel should at least produce some interesting comparisons between different rigs.

Best wishes,

Owen.

THE BRUCE TANK

by

EDMOND BRUCE

Lewis Cove, Hance Road, Fair Haven, N.J., U.S.A.

Introduction. This article describes a test tank which is only 10 feet long, 2 feet wide and 1 foot deep which has been used for 15 years to test over 200 model hulls. Where it has been possible to check the figures produced by the tank against full size craft, they have been found to be accurate and useful to yacht designers.

The basic principles behind the testing of models of larger craft in a tank and of finding out the resistances which may be expected at full scale have been dealt with in A.Y.R.S. No. 24 but they will again be stated here in a summarized form.

The total resistance of a hull is composed of two factors, skin friction and " pressure resistance " (made up of wave-making resistance and " form " resistance). These two resistances were shown by Froude to be apparently quite separate from each other. In a model in the tank, therefore, the objective is to find out these two factors separately, enlarge them separately and again add them to find out the full scale resistance.

In the conventional tank, the same Froude number is used both for the model and the full scale craft so that the " pressure resistance " of the full scale craft will be that of the model multiplied by the cube of the " scale factor." Skin friction, on the other hand, cannot be scaled up in the same way, though there is an approximate correspondence to Reynolds number. In fact, the skin of the model is measured in effective length and area and its resistance is calculated. Then, by scaling up by Reynolds number and using the empirically derived Schoenherr curve, the full scale skin friction can be calculated. Both the model and full scale skin resistances will lie along the Schoenherr curve if they are both turbulent. Now, the full scale craft will have turbulent boundary layer flow but a small model will have a large area near the bow which is in " laminar " flow and this will make the skin resistance different from the Schoenherr curve. It is therefore the practice to cause the boundary layer of the model to become turbulent by adding trip wires, studs or sandpaper to the bow or by other means.

Now, it has never been questioned that Froude's law of comparison holds truly for the smallest models and, if the " pressure resistance " could be found for them by an accurate discovery of the skin friction, the pressure resistance of the full scale craft could be found. The skin friction of the larger craft can then be calculated from the effective length and area of the wetted surface and thus the total resistance produced.

The theory on which the tank which is being described here is founded is that the models are so small that they are entirely in a state of " laminar flow " in their boundary layers which is a stable condition. As the models (or the Reynolds numbers) get larger, turbulent flow begins to appear at the sterns and this is rather unstable in its resistance so the models must be small enough to prevent turbulent flow altogether. Firstly the model is towed in the tank and its resistance found. Then, a plastic " skin " of the shape and area of the wetted surface of the model is towed and the resistance found. The difference between these two resistances gives the " pressure resistance" of the model.

The Tank's Background. The late Professor Davidson, of the Stevens Tank, was a class mate of mine years ago and, more recently, I have had helpful arguments with him about basic methods. In fact, these arguments and my convictions founded my hobby for me.

The consequences of an inexpensive tank method could be frightening to professional tank people and there is a controversial aspect to all ship model testing no matter where or by what method it is done but it is felt that adequate evidence will be given here to show that a small tank which tests models in laminar flow can give accurate results.

Davidson was well aware of my private tests and, in return for supplying me with copies of many Stevens reports on sailing hulls. he requested that I not publish my views. He felt that, if small tanks sprang up everywhere, his life would become miserable combatting misinformation from unskilled experimenters. Since his recent passing, I no longer feel bound by this undertaking and I never agreed with Davidson's viewpoint on the ills of widespread tank experiments.

With my tank, I have been quietly helping certain naval architects for years with a few of their problems where they interest me and I am proud to say that every effort so far has been successful at full size. To give just one example, I was able to show Mr. Henry A. Scheel that a marked improvement could be obtained in pointing, footing and balance with multiple adjustable centreboards in addition to a fixed keel. The higher lateral lift-drag ratio is largely responsible for the racing successes of the boat he had built and which he described in an article in the September 1958 RUDDER where he acknowledges the help given him by the tank.

The Wave Resistances. In this tank, the total resistances of models, when reduced by their skin resistances (found separately), at the same speed, produce pressure resistance values which check Froude's "similitude" law very well. This was determined by tests on three sizes of models which were similar in shape and had their weights proportionately scaled. This is substantial encouragement for the worth of the method and is the type of experiment I would recommend to those just starting in tank testing.

The Skin Resistances. It is on the method of measurement of the skin resistances of the model hulls tested that this method differs from the orthodox. In short, the skin friction of the model hulls is tested by cutting out a sheet of polyethylene film 0.012 inches thick to the shape of the skin of the hull, including all small appendages to scale such as rudders, keel etc., so that their low Reynolds numbers compared to that of the main hull are properly accounted for.

This floats on water and is towed down the tank by a string attached to its upper forward surface.

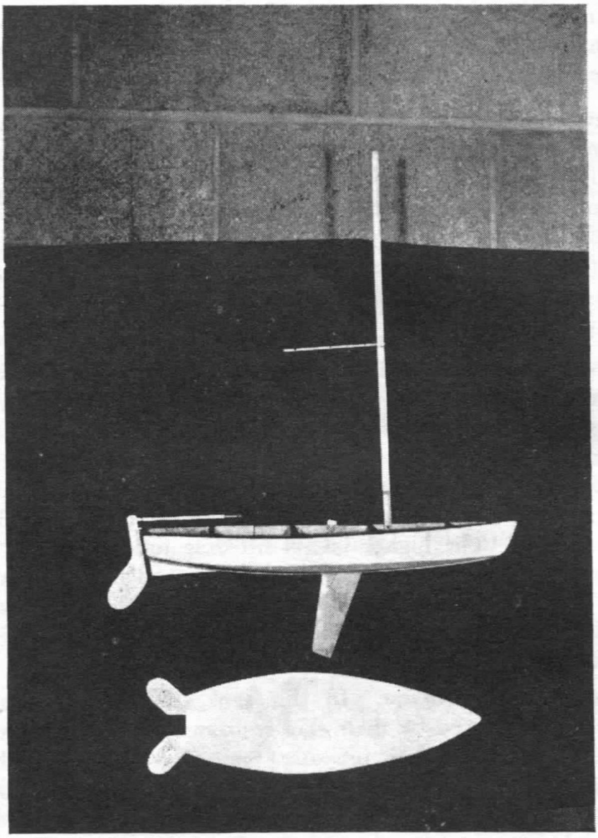


Fig. 1. *Model and " Skin."*

The centreline of the skin can represent the waterline on the two sides of the hull but joined together. Further out on each side is the reproduction of the side surface of the keel with the rudder similarly produced aft.

The laminar *theoretical* work by Blasius indicates a resistance coefficient versus Reynold's Number which is precisely parallel to my *experimental* data, even throughout a range of water temperatures, when plotted on log-log scales. This slope or exponent is my indication of laminar flow. The transition and turbulent regions have slopes which are quite different. My proportionality factor is slightly higher than Blasius but so is data I have obtained from the U.S. Model Testing Basin.

Theoretical Skin Friction. It is usual to plot the coefficients of skin friction against Reynolds Number, the reason for this being given in many text books. It gives the skin resistance in a straight line on a log-log plot. Its slope therefore indicates the exponent and its base intercept, the proportionality.

The coefficient is represented by :

$$C_f = \frac{R_f}{\rho/_2 \, Sv^2}$$

where R_f is the total frictional resistance in pounds.

S is the wetted surface in square feet.

v is the velocity in feet per second.

ρ is the fluid density in pounds per cubic foot divided by the acceleration of gravity in feet per second per second.

The Reynolds' number is written :

$$R_e = \frac{vL}{\mu/\rho}$$

where L is the effective length in feet in the direction of motion.

μ/ρ is the kinematic viscosity of water allowing for temperature and type of water.

In the figures, the line on the right is a reproduction of the well-known Schoenherr curve for the region of complete turbulence. Schoenherr assembled experimental data from many sources and plotted them all. His line is the mean drawn through them. It is reported to be nearly completely turbulent from $R_e = 2x\ 10^6$ upward. Below this and down to about 2.5×10^5, added stimulation is usually needed to force the water to full turbulence. Still lower, full turbulence is not possible.

The line on the left is the Blasius theoretical laminar curve but with E. H. Lewitt's slightly modified proportionality factor. It is written :

$$Cf = \frac{1.369}{\sqrt{Re}}$$

In the figure and above Blasius' curve are some of my early data. These were obtained from two " tear-drop " shapes of polyethylene of similar shape but 12 and 15 inches long respectively. The Reynolds'

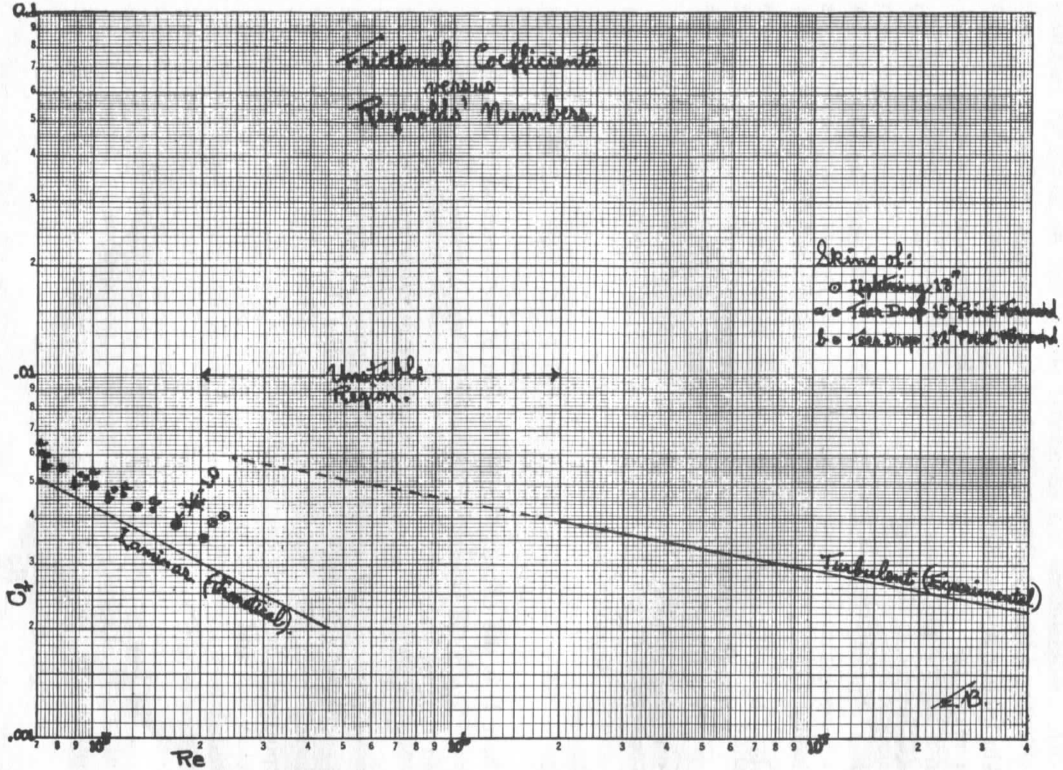


Fig. 2. Blasius' and Schoenherr's curves with experimental plot.

Number implies that they will have the same coefficient of resistance if vL is the same and the correspondence is quite satisfactory. However, when these skins were reversed and towed blunt end first, instead of the fine end first as was done for the figures in the graph, the resistance coefficient increased by 16 per cent., although the slope was the same. This was due to the blunt forward shape extending beyond the " Mach angle " of the water's advance ripple pattern. Few hulls are this blunt, but this circumstance should be avoided.

The Skin Testing Method. Whereas large tanks usually make measurements of skin friction from planks on edge suspended from an overhead carriage there are problems of the finite thickness of the planks and of longitudinal flutter in thin planks. For this reason, I abandoned this approach in favour of thin polyethylene films positioned horizontally on the water's surface. Support is obtained both fron the materials' buoyancy and from the surface tension of the water. Tests of ribbon-like surfaces were abandoned also in favour of the model hull's actual wetted surface area laid out on a flat film by transference of adjusted girth measurements at various station locations. For accurate testing of skins, it is essential to keep the towing cord out of the water. For this reason the cord is given a 10° rise but only the horizontal component is used for calculations.

It has been interesting to discover that films 0.002 inches thick measure the same as films of identical size and shape but 0.012 inches thick. Vinylite and cellulose-acetate gives the same results as polyethylene. Waxing or oiling the surface produces no measurable changes. The only thing which seems to alter the resistance is silicone grease which makes it greater. However, exposure of the tank water to daylight for three days or more grows algae and this increases frictional resistance which makes a change of water and tank cleaning important. This is an additional argument for a small tank as it is an annoying chore. Covering the tank with a light-proof cover is helpful, as are anti-algar preparations used in swimming pools.

The earliest model tested was a *Lightning* class sailboat. By chance, the skin representing the model's wetted surface was 18 inches in total length. The measured data for this skin, at the usual displacement speed-length ratios, is plotted on the attached curve sheet. They show that the model is slightly too large for the top speeds. Up to a Reynolds number of 2 x 10^5, the experimental slope is the same as the theoretical laminar curve and therefore considered stable. Instability sets in beyond this which sometimes cannot be repeated in successive runs. I no longer use models as large as this.

Experience has taught me that the average length, rather than total length, must be used for Reynolds numbers. This is obtained by dividing the area by the extreme width of the skin. This pulls most data, with a few exceptions to the same line, which would otherwise appear scattered. This means that the shape of the skin is important.

Water temperature is extremely important. If the proper viscosity values are used in the Reynolds Number, the alignment of data will be quite satisfactory. Several tests with progressive temperatures obtained by heating the water electrically, confirm this. An electrical heating cable is placed in spiral fashion on the bottom of the tank to adjust the temperature.

Every model I test has a separate skin test to determine the component of frictional resistance versus speed. Displacement types have nearly constant wetted areas as their speeds are varied. Planing types, on the other hand, have areas which vary with speed and they need special consideration. The laminar curve illustrated with a plotting of points is used only to check that the frictional coefficients have not strayed from the purely laminar region. However, even if the skin departs from the laminar state, the pressure resistance can still be determined correctly provided the hull surface and the separate skin behave in the same manner.

The Calculations. For a given speed, one first finds the total resistance of the model hull and the resistance of the skin separately. The difference between these two figures gives the pressure resistance. The pressure resistance is scaled up to full size by Froude's " similitude " law. The effective skin length of the model is found by dividing the area of skin by the greatest width. For the same speed, one can then calculate from Schoenherr's curve the full sized frictional resistance precisely as the commercial tanks do and add it to the pressure resistance transferred to full size by the Froude ratio. This gives the expected total resistance of the full sized craft.

THE TANK

Commercial tanks provide enough tank length for the acceleration and deceleration of their heavy overhead carriages which support the models. We do not have this problem since floating models towed by a fine cord are used. Continuous photo-electric, automatic recording of travel time in units of 1/100th second for every two inches of the tank length permits not only the measurement of speed but also of acceleration.

The horizontal towing force of the cord is derived from a falling weight via a low friction pulley. This force has two additive parts. One overcomes the model resistance in the water at the momentary speed and the other accelerates the model. If we wait long enough so that the acceleration is zero, the falling weight will represent the water resistance alone. For the size of models we must employ to remain in the region of laminar flow, acceleration to maximum speed can be accomplished in about eight feet or less. However, if the ultimate speed is not obtained for any reason the acceleration remaining times the mass of the model with pulley correction indicates the force which should be subtracted from the falling weight to give the model resistance for the speed developed. Ideally, one run from a standing start is all that is needed for a range of resistances versus speeds but actually a series of weights is used to give greater accuracy.

Tank experts tell us that to avoid appreciable wall effects, the cross-section of the tank should be more than 100 time the cross-section of the underwater body of the model. This means that for our size of models, a tank 2 feet wide by 1 foot deep is ample. To accommodate the length of the model plus the travel distance, therefore, the tank need be only 10 feet long if an arrestor cord is used at the terminal. This is an astonishingly small tank by prevailing standards, but we cannot beneficially employ a larger one with our laminar method.

Accuracy in a tank test usually requires still water. Waiting for waves and ripples to die down is time consuming with a tank having hard walls. In an attempt to damp down the wave motion somewhat more rapidly, my tank is made of flexible Vinylite only 0.012 inches thick. It is mounted on a skeleton frame and the bottom rests on a platform. This supports the weight of water and relieves heavy cumulative strains through the Vinylite. A friend of mine slapped a bulging side and remarked that it reminded him of spanking the baby.

The Vinylite has a surface which is slightly rough optically which makes it translucent. When this surface is in contact with water on the inside and a smear of Canada balsam is put on the outside, a satisfactory window is provided which permits looking at the underside of a hull to examine the water action. If powdered resin or aluminium powder is sparingly mixed in the water, it makes possible the observation of water adjacent to the hull surface in search of harmful eddies.

Mechanically pulsing one flexible end of the tank gently, generates

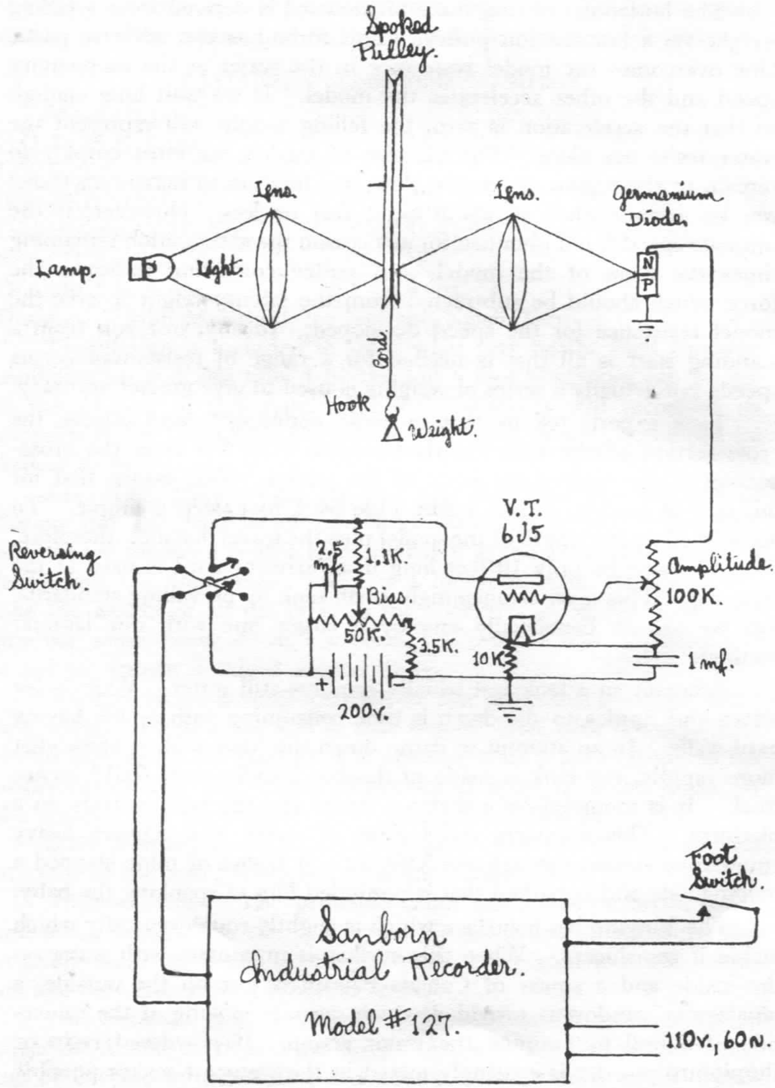


Fig. 3. Timing mechanism.

waves which are useful for visual observations of rough water performance. Accurate measurements under these conditions are, however, not easy.

A tank at ground level is an abomination. Frequent stopping to adjust a model is a back-breaking thing and if the tank is raised so that the water surface is breast-high, the experiments will be much happier.

Since we will make tests of sailing hulls, among others, running, reaching and windward courses must be studied. These require that the towing force, which simulates the direction of the sail force, must be in various directions. To take care of this, my tank is rotatable horizontally. This permits a fixed location for the towing and recording equipment. It is not wise to turn a full tank when it contains 1250 pounds of slopping water but, when partially full, clusters of three small castors under each of the six legs make it easy on the concrete floor. Filling with water is via a hose which is also used for emptying by siphon action to a floor drain.

Thus, the tank proper is simplicity itself and quite inexpensive. It has served for 12 years without repair.

THE TOWING AND TIMING MECHANISMS

Timing the events with a hand stop watch is much too crude.

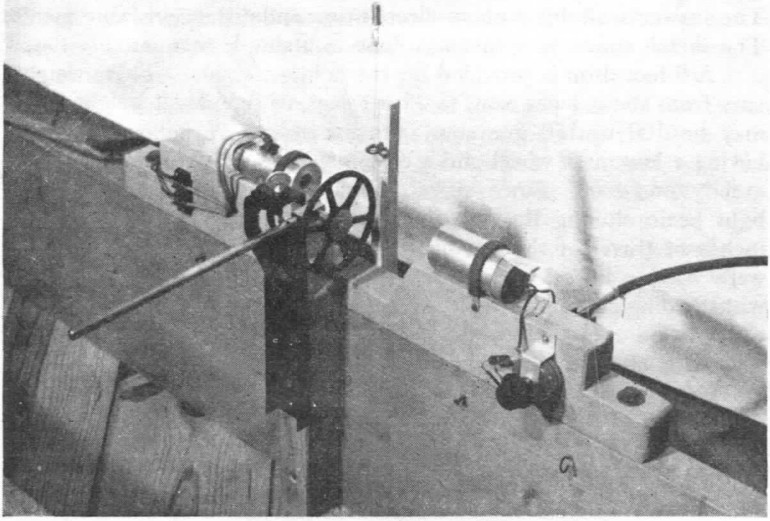


Fig. 4. Photograph of pulley and photoelectric units.

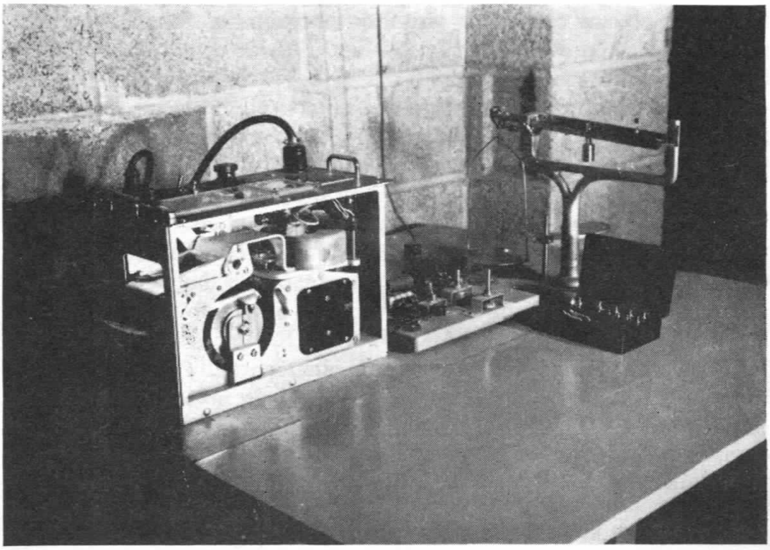


Fig. 5. *Timing recorder.*

One needs an accuracy of 1/100th second rather than 1/5th second. With such precision in timing, no personal reaction time must be involved in determining the time between departure and arrival. The answer to all this is photo-electric time and distance measurements. The sketch shows how this was done in a simple manner.

A 9 foot drop is provided for the falling weights. These weights vary from about 1 per cent. to 25 per cent. of the model weight which may be 100 to 150 grammes in usual cases. A pulley was made having a low mass wheel and a circumference in its groove of almost exactly one foot. Since six accurately spaced spokes are used, a light beam shining through them is interrupted once in every two inches of travel of the towing cord. Tiny instrument ball-bearings were used. These were selected as being much more rugged in withstanding heavy bearing loads and abuse rather than needle bearings which were measured to have less rolling resistance. The rolling resistance of the ball-bearings was measured for a range of bearing loads and proved to be far less than one per cent. of the weight used in all cases.

The linear filament of a small lamp is focused on a spoke of the pulley by means of a simple lens. Beyond the pulley, another lens refocuses the unobstructed image on a germanium (or silicon) P-N junction.

The normal high electrical impedance of the reversed bias, solid-state junction is greatly reduced every time light impinges on it. The voltage variation across an adjustable potentiometer in the circuit is fed to a vacuum tube (valve). This, in turn, amplifies the current so that it will actuate the stylus of a Sanborn industrial automatic recorder, Model 127, having an accurately timed graph-paper feed.

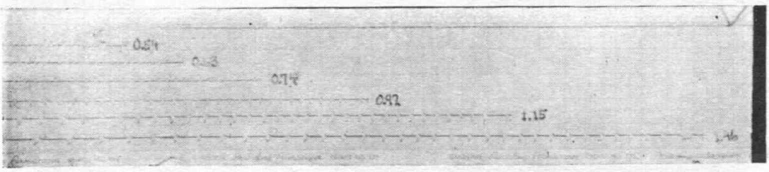


Fig. 6. Timing record, six runs.

Full scale deflection of this recorder, each side of centre, requires 25 milliamperes. A variable bias and reversing switch is shown so that the recording stylus can be adjusted to any part of the width of the paper. By doing this, as many as ten runs can be indicated in parallel on a short strip of the recording paper for comparison and economy reasons. The recorder paper-drive is started and stopped by a foot-actuated switch at the model's starting location.

Since timing can be measured to an accuracy of about 1 per cent. for a one second interval, the overall accuracy can be expected to be within experimental errors.

TEST RESULTS

With No Leeway. Tests on power boat models should have the towing cord attachment aligned with the propellor shaft. For tests of sailing models, a stub mast supporting an elevated horizontal rod is used and so arranged as to permit cord attachment at a point which corresponds to the exact force centre of sail effort. The examples given here will be from tests of models of the *Lightning* class which is an old and well known class boat with numbers approaching 10,000.

When a *Lightning* is on a running course, a mainsail and boomed out jib would be slightly unbalanced. For simplicity, however, let us consider the more balanced case which can be achieved when the spinnaker is used. The graphs and figures show the actual data of such a test on a model *Lightning* with a crew of three so placed as to have no heel. A centered helm is used with no centreboard lowered, The skin test for this model was not stable much beyond $\frac{V}{\sqrt{L}} = 1.1.$

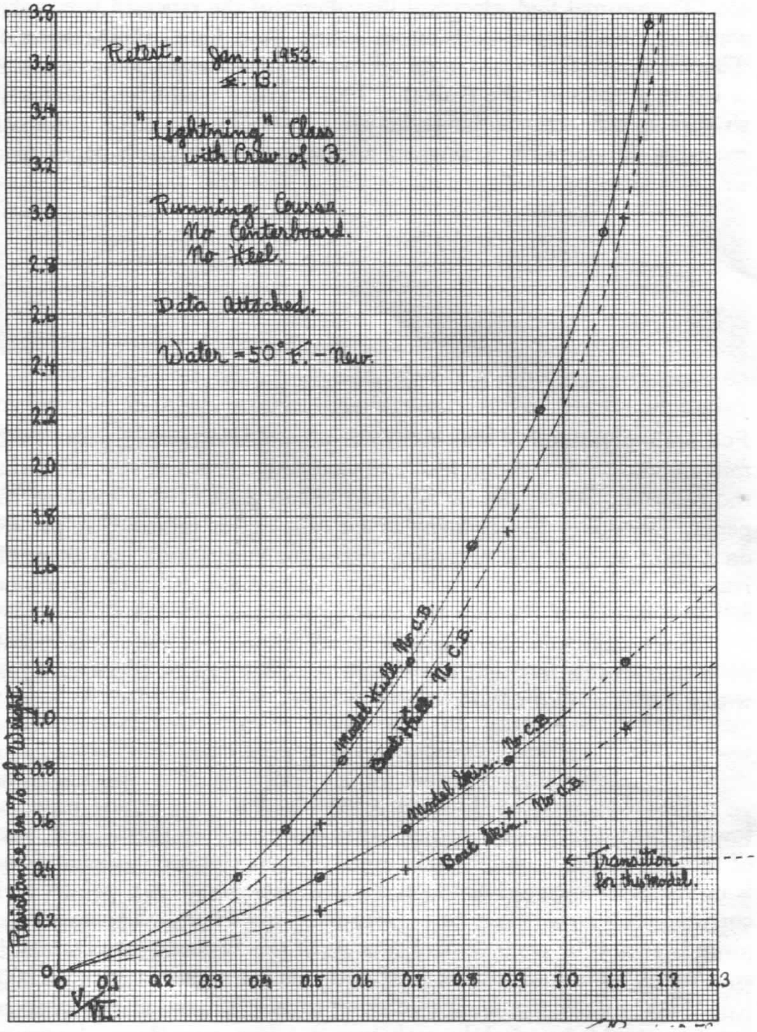


Fig. 7. " Lightning " model results with estimated full sized resistances.

a point which was discussed previously. However, resulting errors may be overshadowed by the high pressure resistances encountered at these speeds.

The data sheets give an opportunity for a detailed study of the method and are better than a lengthy word description. I should

Jan. 1, 1953. Retest (Copy). E.B. 6-10-59. "Lightning" Class with Crew of Three. Running Course : No Centreboard. No Heel. Scale : 12 : 1.

Water : Clean, 50° F. $\frac{\mu}{\rho} = 1.41 \times 10^{-5}$

	Boat	Model	Comment :
Lightning Wt.	820 pounds	215 grams.	Retest for
Crew Wt.	450 ,,	118 ,,	confirmation
Total Wt.	1270 ,,	333 ,,	of 1945 data
L.W.L.	16.0 feet.	1.33 feet.	
Skin $L_{av.}$ with Rudder	13.3 ,,	1.11 ,,	
Skin Area with Rudder	72.0 sq. ft.	0.50 sq. ft.	

Model R. & Rf.								
Pull Wt. No.	2	4	7	11	16	22	29	38
Pull Grams.	1.22	1.88	2.79	4.08	5.63	7.48	9.83	12.63
$\frac{\text{Resistance}}{\text{Weight}}$ in %	0.363	0.560	0.831	1.22	1.68	2.22	2.93	3.76
Model Hull Tests.								
Secs./Ft.	1.46	1.15	0.92	0.74	0.63	0.54	0.48	0.44
v in Ft./secs.	0.686	0.870	1.09	1.35	1.59	1.85	2.09	2.27
V in Knots	0.406	0.515	0.645	0.799	0.941	1.095	1.24	1.34
$V/\sqrt{L}$	0.353	0.448	0.561	0.695	0.818	0.953	1.08	1.17
Model Skin Tests.								
Secs./Ft.	1.00	0.75	0.58	0.46				
v in Ft./Secs	1.00	1.33	1.72	2.17				
V in Knots	0.593	0.787	1.02	1.29				
$V/\sqrt{L}$	0.516	0.684	0.887	1.12				
Full Size Skin Calculation								
Equiv. v in Ft./Sec.	3.47	4.61	5.95	7.52				
v x $L_{av.}$	46.2	61.3	79.1	100				
Reyn. No. = x 10^6	3.27	4.35	5.61	7.10				
Schnhr Cf	.00036	0.0034	0.0032	0.0031				
Rf in lbs.	3.02	5.03	7.89	12.2				
Resistance/ Wt. in %	0.238	0.396	0.622	0.956				
$\frac{Rf}{W} - \frac{Rf}{W}$ in %	0.125	0.164	0.209	0.266				
Correction Reqd.								

Notes : $R_f = C_f \frac{\rho}{2} A. v^2.$

$Re = \frac{v.\ L_{av.}}{\mu/\rho}$

Froude Law of Comparison :

$\frac{V}{\sqrt{L}} = k \frac{Rp}{W}$

$Rp = R - Rf.$

comment, however, that the *Lightning* is a notoriously slow runner although, when beating to windward, it is a reasonably good boat due to a centreboard having a high aspect ratio. Its hull is beamy and has a hard chine with a large amount of wetted surface for its displacement. Considerably less running resistance has been observed in the tests of a number of models of other boats.

With Leeway simulating Close Hauled Courses. If we consider a well balanced and properly trimmed sailboat hard on the wind, the close windedness of the boat to the apparent wind will depend, disregarding speed, only on the magnitudes of the lateral lift-drag ratios of both sails and hull. This can be calculated readily from a sailing action and reaction force diagram, if desired. Such calculations emphasize the importance of hull research for windward situations since they have fallen so far behind sails in merit. Since we are presently discussing hulls, rather than sails, we may wish to know what is the highest lateral lift-drag ratio a particular hull can achieve, this ratio being that of the forces at right angles to and in line with the course made good.

The flyers of kites, who are familiar with the scientific theories, are well aware that the more nearly vertical the cord to the kite, the better is the kite. In other words, the higher is its lift/drag ratio, which is defined by the tangent of the cord angle to the horizontal. The same technique can be used to " fly " the sailing hull laterally.

The more nearly the cord pull can approach being perpendicular to the course made good by the hull, (not to the heading which is greater by the angle of attack) the higher is its lateral lift-drag ratio. This angular limit can be measured. Since it is so close to the type of stalling called " in irons ", the measurement of speed is rather meaningless. Speed can be measured later at a lesser cord angle to promote greater stability in comparative measurements.

The place of cord attachment to the model, for windward tests, is elevated to a height which corresponds to that of the force centre of sail effort. Also, it must be carefully adjusted fore and aft along a horizontal rod which is supported at this height by a stub mast. This rod is aligned parallel with the centreline of the hull for the test.

Hull balance is achieved when the attachment is vertically above the centre of lateral resistance of the hull when optimum speed has been reached. In this position, the hull will travel in a straight line. It will assume an angle of heel, of yaw and of pitch precisely like the full size boat under the same conditions. When the attachment is improperly adjusted, the hull will turn either high or low of the course.

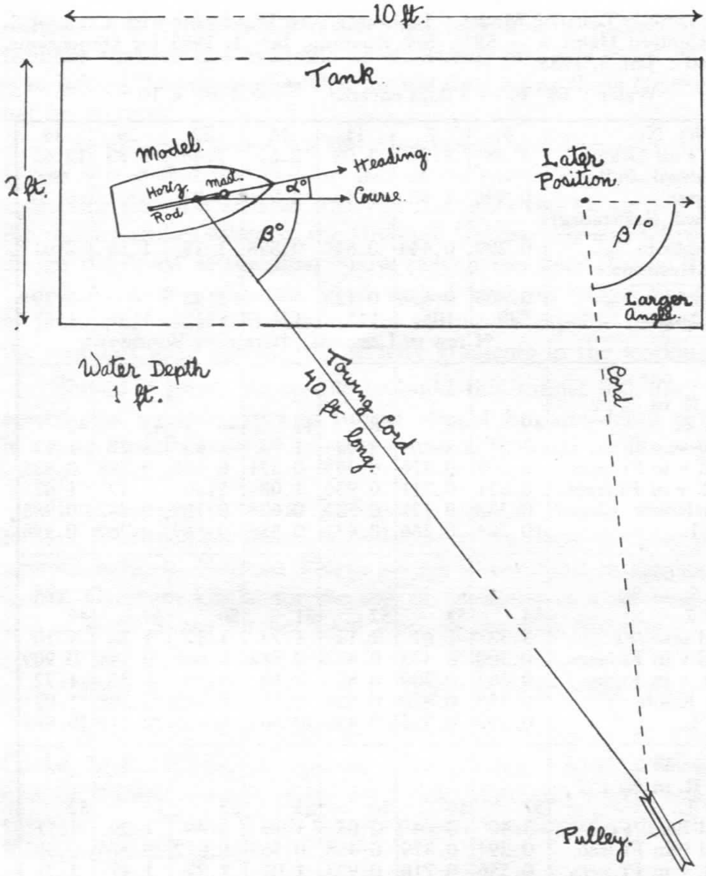


Fig. 8. Method of close-hauled testing.

In this tank, the towing mechanism will provide horizontal pull via a long, fine nylon thread, 40 feet long, this length being used to minimize the change in angle of the course to the towing cord as shown in the attached sketch. Its attachment point will be indicated by the percentage of waterline length measured from the bow. With the hull balanced, this pull will be adjusted in a direction as nearly perpendicular to the course as we can make it without stalling the model's progress. An optimum positioning of both the centreboard and the helm will contribute towards our success.

Such tests were made on our *Lightning* model with the leading edge of its centreboard fixed at $67\frac{1}{2}^\circ$ from the waterline and the helm

Bruce Tank. Tests of Model " Lightning " to Windward with Crew of 3. using Centred Helm $\beta = 58°$. See Running, Jan. 1, 1953 for Dimensions. Retested : Jan. 3, 1953.

Water : 69° F. — 3 days covered. $\frac{\mu}{\rho} = 1.07 \times 10^{-5}$

Pull Wt. No.	4	7	11	16	22	29	38
Total Pull Grams.	1.88	2.79	4.08	5.63	7.48	9.83	12.63
58° Forwd. Pull Grams.	0.996	1.48	2.16	2.99	3.97	5.21	6.70
58° Fwd. Resistance/Weight in %	0.299	0.444	0.649	0.898	1.19	1.56	2.01
Total Resistance/Weight in %	0.565	0.838	0.123	—	2.25	—	3.79
Heel Angle	*9°	10°	11°	12°	12½°	†13°	†15°
	*Crew to Leeward †Crew to Windward.						
C.B. = 90°							
C.L.R. in % L.W.L.	49	49	48	47	46	45	42
Cord secs./Ft.	3.31	2.66	2.02	1.75	1.46	1.27	1.13
Cord v in Ft./secs.	0.302	0.376	0.495	0.571	0.685	0.788	0.885
Fwd. v in Ft./secs.	0.571	0.711	0.936	1.08	1.30	1.49	1.67
V in Knots	0.338	0.421	0.554	0.639	0.769	0.882	0.988
$V/\sqrt{L}$	‡0.294	0.366	‡0.482	0.556	‡0.669	0.767	0.858
C.B. = 67½°							
C.L.R. in % L.W.L.	54	52	52	51	50	49	47
Cord secs./Ft.	3.33	2.67	2.12	1.72	1.47	1.26	1.10
Cord v in Ft./secs.	0.300	0.375	0.472	0.582	0.681	0.794	0.909
Fwd. v in Ft/sec.	0.567	0.709	0.892	1.10	1.29	1.50	1.72
V in Knots	0.336	0.420	0.528	0.651	0.763	0.888	1.02
$V/\sqrt{L}$.	0.292	0.365	0.459	‡0.567	0.665	‡0.772	‡0.887
C.B. = 45°							
C.L.R. in % L.W.L.	57	56	56	55	55	54	52
Cord Secs./Ft.	3.40	2.64	2.05	1.77	1.49	1.29	1.11
Cord v in Ft./sec.	0.294	0.379	0.488	0.565	0.672	0.776	0.902
Fwd. v in Ft./secs.	0.556	0.716	0.923	1.07	1.27	1.47	1.71
V in Knots	0.329	0.424	0.547	0.633	0.751	0.870	1.01
$V/\sqrt{L}$.	0.286	‡0.369	0.476	0.551	0.653	0.757	0.878
	‡ Highest.						
Maximum Possible Cord Angle $\beta°$ with Centreboard fixed at 67½°.							
$\beta°$	76°	77°	77½°	—	78°	—	78°
C.L.R. in % L.W.L.	58	58	58	—	58	—	58
Max. Lateral Lift/Drag.	4.0	4.3	4 5	—	4 7	—	4.7

Wetted Areas :	Model	Boat
Hull and Rudder sq. ft.	0.50	72.0
67½° Centreboard sq. ft.	0.079	11.3

Model Hull — 50°ρ $V/\sqrt{L}$.

Running — R/W = 1.68%

No C.B. 0.818 Copy E.B.

67½° C.B. 0.795 Oct. 28, 1959.

From Running Hull Curve : $\triangle R/W = 0.11\%$ C.B. Effect.

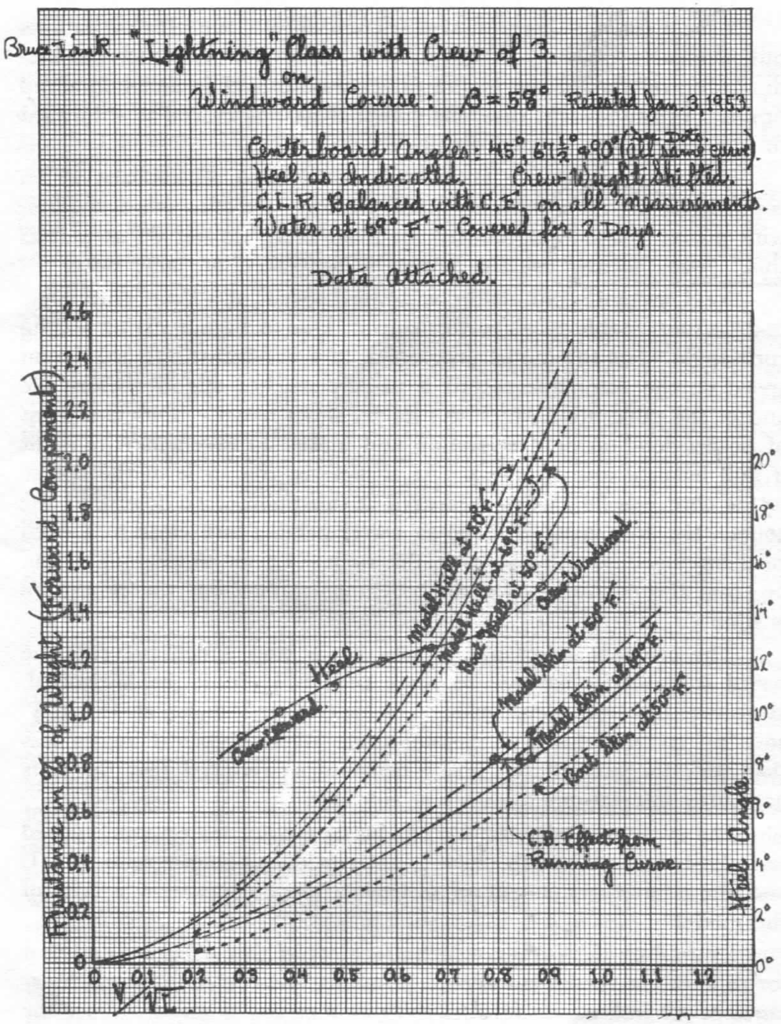


Fig. 9. Model and full size resistances adjusted for temperature.

fixed amidships. The resulting measurements will be found in the data sheet opposite. The range of towing force appears at the top of this sheet and the maximum cord angles and lift-drag ratios at the bottom. A curve of this data is drawn on the graph. It is seen that the optimum lateral lift-drag ratio, for these adjustments, varies between 4.0 and 4.7 for the range of forces.

Except for the effects of skin friction, ideally the lift-drag ratio is independent of speed. It is often the case, however, that the lift-drag ratio falls off at the higher forces due to heeling and hull speed limits. In the present case, the crew ballast was moved to windward to avoid heeling as is good dinghy practice.

The *Lightning* has a good high aspect ratio centreboard which contributes to its windward performance. Certain other models, with poorer shaped centreboard, or fixed keels, do not do as well as this. Also, heeling usually cannot be prevented on large boats.

Next, we will examine the windward speeds at a lesser cord angle to get a more stable speed performance. Due to a gradually increasing cord angle β° as the model progresses, in a windward test, maximum speed on the automatic record is usually reached slightly before the end of the tank, after which the model slows down. This is a point of no acceleration or deceleration and makes an excellent data point if hull balance was achieved. At all speeds, the angle of the course to the cord was 58°, when measured at this point. To determine the course, the stub mast is made to travel parallel and close to a fixed cord stretched lengthwise over the tank. Lesser angles for β can be used for measuring various reaching courses but the procedure is similar.

The centreboard of a *Lightning* has a stop which prevents the board from being lowered to more than $67\frac{1}{2}^\circ$ from the horizontal. However, the tests were made with centreboard angles at 45°, $67\frac{1}{2}^\circ$ and 90° to investigate all possibilities. At centreboard angles less than 45°, the area of the board becomes so reduced that the tests have little interest due to excessive side slip.

For every test run, the C.L.R. balance point for optimum speed is indicated on the data sheet ; also its speed-length ratio $V/\sqrt{L}$ and the course component of resistance in percentage of weight of the model.

Examining the curves, which are plots of this data, we find that for each of the three centreboard positions, the centre of lateral resistance of the hull moves forward with an increase of speed. Since the centre of force effort of properly trimmed sails will vary only a little with varying wind strengths, we must maintain our point of balance principally by adjustment of the centreboard.

The positions for the centre of sail effort are examined on the plot. Remembering that we cannot lower the board beyond $67\frac{1}{2}^\circ$, we find a better range of centreboard adjustment when the centre of effort is 54 per cent. of the waterline length rather than 52 per cent. At 52 per cent, we would be plagued with an excessive lee helm in

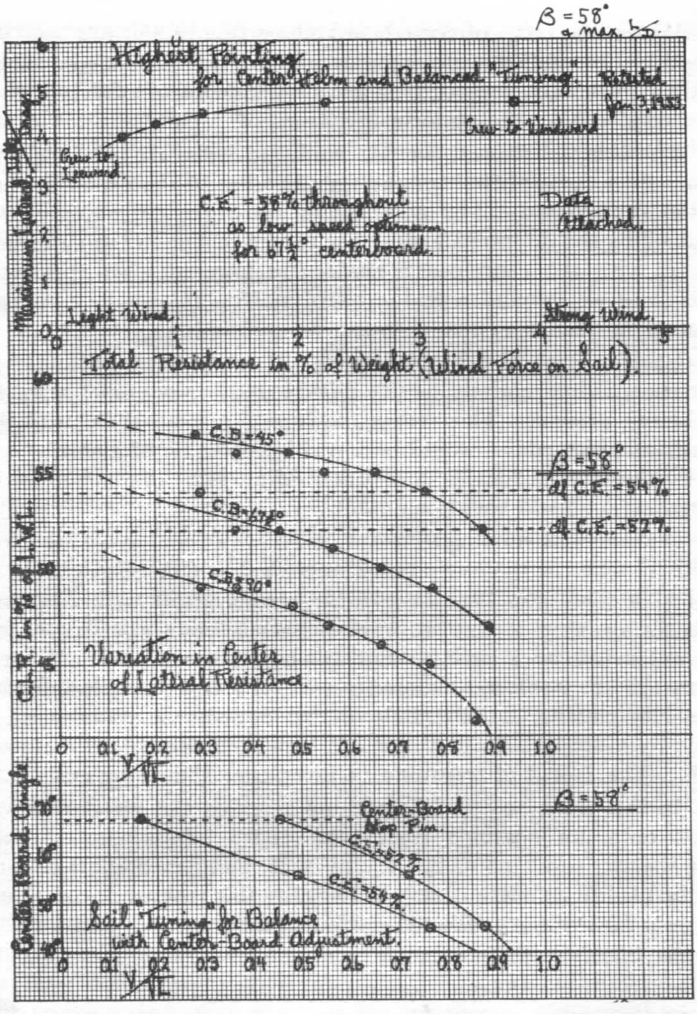


Fig. 10. *Tests for* (1) *Pointing* (2) *Position of C.L.R.* (3) *C.B. Angle.*

light airs. Thus 54 per cent. of the waterline length for the centre of effort appears to be a good tuning position for the sails on a *Lightning*. The centreboard angle required for various speeds, to obtain balance, is plotted on the accompanying graph sheet. This general type of test has been a favourite of designer friends for larger boats. They laid out their sail plans accordingly and have obtained balances, without risk, which delighted them.

Within the range of centreboard adjustment of 45°, 67½° and 90°, the data sheet indicates no significant hull speed advantages for any of these positions, provided balance is maintained. Below 45°, as mentioned before, the performance drops off rapidly.

The skin resistances, for the windward tests, are shown slightly higher than those of the running tests because of the added presence of the centreboard. The centreboard resistance versus speed was obtained by the differential resistance on the model hull, on a running course, with the centreboard raised and lowered. No appreciable differences were found with the board at 45°, 67½° or 90°, probably because the change in area is so small.

Looking back at this old data, I now regret having assigned the centreboard drag entirely to the skin resistance, as eddies were undoubtedly present. This worry, however, is more theoretical than numerical since eddies would be a small proportion of a small "scaling" correction. Ideally, a separate windward skin, including the centreboard, should have been used.

Our previous running tests were made with water at a temperature of 50° F. whereas these windward tests were at 69°. Corrections are applied to this later data to give the results at 50° for comparison with the running tests. Study of these curves reveals that heating the water can be a tool for minimizing "scale effect." Water at about 100° F. would do reasonably well, in the present case, for it is near elimination. As alternatives, this adjustment usually can be made by a proper selection of model length or water temperature or both. The region of transition to turbulence should be avoided.

In this short account, I have not revealed the grand windward speed optimum obtained from inter-related adjustments of helm, centreboard, trim and C.E. If any tank builders finds this out, I will be glad to compare data. In my case, this tank work contributed eighteen *Lightning* trophies to my trophy cabinet.

SOME GENERAL RESULTS

I have found in running tests that short, fat hulls with their maximum cross section forward of amidships are best at very low speeds. At somewhat higher speeds, the maximum sectional area must be reduced and its location placed further aft. Catamarans with narrow semi-circular sections and low prismatic coefficients excel in running resistances in the range of about $V/\sqrt{L} = 1$ to 3. Where, in this range, each excels depends on their L/B ratio. A single hull with outriggers, barely immersed is faster than similarly shaped, optimally spaced twin hulls when the two craft are equal in weight and sail area. To be exactly similar in shape, and equal in weight, twin hulls would be about 79 per cent. of the length of the single hull. However, if comparison is made on a speed basis of $V/\sqrt{L}$, there is little to choose between them since this ratio handicaps length. Beyond $V/\sqrt{L} = 3$, the good planers take over in minimum running resistance. First the soft chine planers excell, followed by the hard chine planers at greater speeds. At very high speeds, the stepped planers and three pointers run neck and neck. I am having trouble making hydrofoils perform near the water surface, though at depth they are fine. My enthusiasm is greatest for the performance of submarines with zero buoyancy. I must again stress that the preceding applies only to running resistances. For windward work, totally different rules may apply.

It is my present belief that, for both displacement and planing hulls, minimum running resistances can be obtained at only one definite speed. When I examine my best model in each speed range, I invariably find that the positive rate of change of frictional resistance just equals the negative rate of change of the combined pressure resistances as certain parameters are varied. It may be a hydrodynamic law.