AYRS 84A

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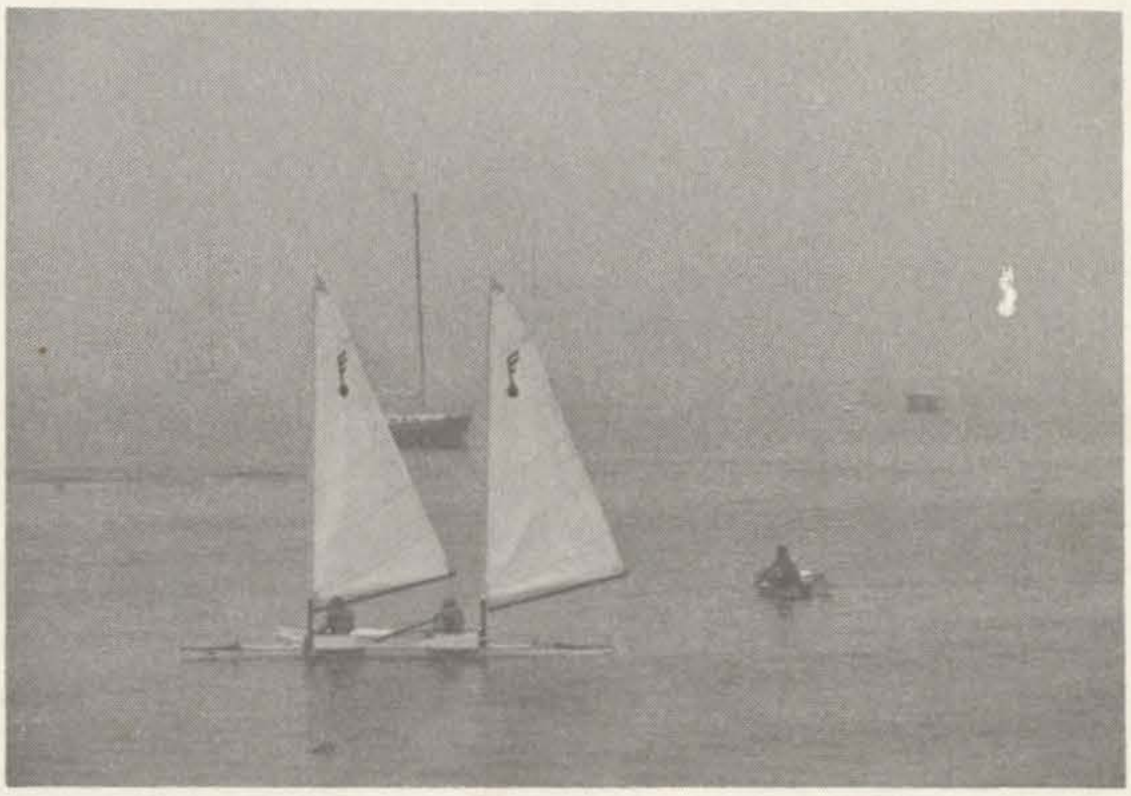
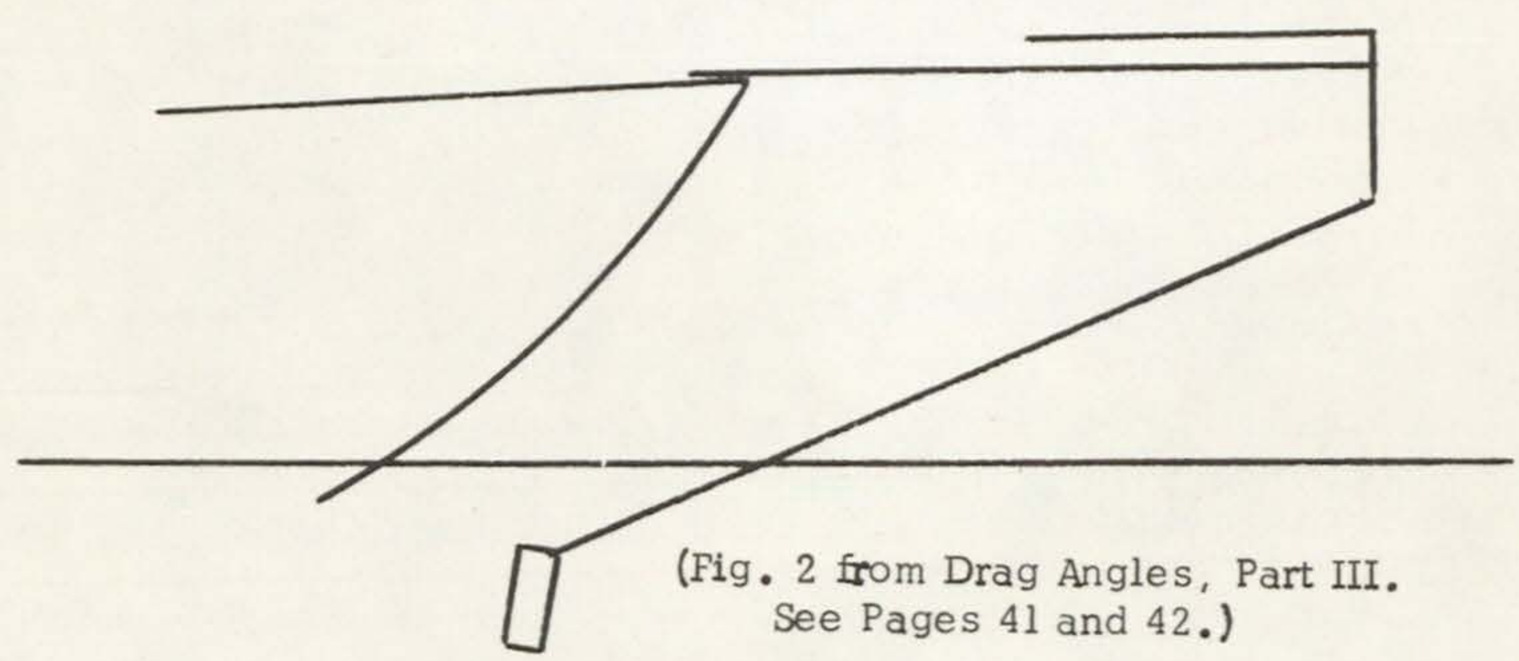
AYRS JOURNAL 84A

HYDROFOILS '76 MAY, 1976

Yacht Research, Design, Science & Technology
Materials and Amateur Boatbuilding
Practical Cruising, Single-Handing, Self-Steering
Sail Rigs, Spars & Rigging
Advanced Craft
AYRS - Florida-Caribbean Contact Group



CONTENTS



(Fig. 2 from Drag Angles, Part III. See Pages 41 and 42.)

AMATEUR YACHT RESEARCH SOCIETY

The AYRS is an international, non-profit society for the amateur yachtsman, boat builder, yacht researcher, inventor, designer, sailor and experimenter. For an annual fee of $15, Members in North and South America receive six issues per year of our bi-monthly Journal plus one book each year edited at AYRS Headquarters in England. Members outside the Americas will receive their Journals two at a time, three times a year. The only requirement for joining is an interest in yachts and their behavior and the hope that Members will share their problems and ideas with others in the form of articles, letters, sketches, drawings and photographs.

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Editor: John W. Shortall III, 10822 92nd Avenue North, Seminole, Florida 33542.
Publisher: Richard A. Kelting, 607 North Cottonwood, Richardson, Texas 75080.

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Editor's Note: I am very happy to announce that in AYRS 84B, our July issue, we publish a 20 page article by John Thomson: "A Lift Study of Some Sailing Hulls." John built a model test tank similar to that of Edmond Bruce's, and this is the result of some five years of work. John has a very different approach to model testing which involves measurement of the hull drag angle, and his work is closely applied to that of Harry Morss. Dick Andrews writes of his own experiments with model hulls using the poor man's test tank: The Whiffletree, and John Morwood sketches out an idea for a recirculating test tank. Joe Norwood concludes his four part series on hydrofoils for sailing craft, and we include another chapter by Harry Morss on drag angles. George Snyder has written in detail on the problems of amateur boatbuilding and on his experiences in constructing a Wharram catamaran.

WORLD MULTIHULL SYMPOSIUM - June 14-17, 1976 - Toronto, Canada - "MULTIHULLS MAGAZINE" 91 Newbury Ave.; No. Quincy, MA 02171. Write the Editor, Charles Chiodi, for more information. Approximately 50% of the AYRS Membership builds or sails multihulls. I would think it extremely valuable for those to attend, and the opportunity to meet designers and hear what they have to say is invaluable. Almost all major multihull designers from throughout the world will be present for this three day affair.

HELP!

Editing and publishing these four bi-monthly issues of the AYRS Journal has been a major volunteer effort on the part of Dick Kelting and myself. For each issue, we have to reject or postpone the publication of some really excellent material due to lack of funds. With the July issue, we will have published some 170 to 180 pages of technical material - some 125,000 words - in six months on our three areas of major concern: yacht science and technology, amateur boatbuilding and cruising research. If we are to continue to donate our time to this major effort, and if those wonderful authors of the 60 or so articles printed are to keep writing, two things are needed: More AYRS Members and more help. After the July issue, we will evaluate the results in terms of how many AYRS Members we have at that time and how much help we have secured. There is not yet sufficient money in the AYRS treasury to be able to hire assistance, and we do all the dog work jobs ourselves.

AYRS MEMBERSHIP.

AYRS Membership worldwide is about 2200 or so, of which perhaps a third or more are from The Americas. Since this is renewal time, we do not have exact figures.

With one U.S. boating magazine having a circulation of 156,000 and others with very substantial figures, it seems reasonable to expect that we could have three or four thousand AYRS Members here. Such would support a considerable improvement in our work and lead to bigger and better publications. Although it would be fun to keep AYRS small like a club, it is an economic fact of publishing life that we need a substantial boost in membership, particularly in The Americas, to justify this effort. If such does not come about, it will be because we are not serving a need. Most sailing people and amateur boatbuilders in The Americas have never heard of the AYRS, and our principal problem may well be to let people here know that there is such a Society. I am very thankful to the many yachting magazines who in the past year have published information on the AYRS - this has helped. We now have a regular column in "MULTIHULLS MAGAZINE," thanks to Charles Chiodi. The firms of ALMAR, Gougeon Bros., and

Harstil have offered to include AYRS literature with their regular mailings to clients and prospects, and I am very grateful. We need more such.

ADVERTISING.

We plan shortly to solicit for advertising in the AYRS Journal under the AYRS policy that such will have no effect on the content. The purpose of this is to secure more revenue for publishing, and I estimate that such would permit us to publish at least one additional book per year for the Members. If any have objections to this, would you please let me know?

PEOPLE.

We are badly in need of help, and it is paradoxical that if we do succeed in helping AYRS to grow in The Americas, we will need even more assistance:

1. DALLAS AREA. Volunteers are needed to assist in the many facets of publishing our Journal: typing, arranging format, address lists, addressing, bundling by zip code for mailing, special mailings abroad, etc.
2. FLORIDA AREA. I need people here to help with the accountings, sales of AYRS books and materials, typing, membership and prospect listings, assist editing, etc.
3. ANY AREA. For Canada, South America, Western U.S., Midwest U.S. and Eastern U.S., we need people to act as local AYRS Organizers in their areas. This can involve only the writing of publicity and membership stimulation or can extend as far as book sales and organization of AYRS contact groups with lectures and sailing meetings.
4. LEGAL. I have taken the first steps to apply for non-profit status for the AYRS in this country. Is there any lawyer-AYRS Member, anywhere in the U.S. who could donate his services to advise on the occasional legal problems that arise?
5. FINANCIAL. We need an AYRS Member to step forward and volunteer to take over the bookkeeping of this operation. While a Florida Member would be preferable, he or she could be anywhere in the U.S.
6. AMERICAN ORGANIZER. Up to now, I have worn two hats for the AYRS: American Organizer and Editor for the Americas. It is time to divest myself of the former job, and I seek someone to take over this function. This will take a day or two each week - less if we can organize on regional lines per paragraph 3, above - and involves publicity, other membership stimulation, book sales and the necessary accountings.
7. COMMITTEE ON YACHT STRENGTH. If this is to come about, we need someone to offer to chair this informal group. It involves the writing of technical letters on this subject, coordinating the efforts of the members and getting out publishable material for the AYRS Journal. See AYRS 83B for Prof. Venable's proposal and his recommendation that the first topic undertaken be the multihull beam problem. The design of stayless, reinforced masts is another major topic of concern.
8. SAILING YACHT RESEARCH CENTER: SYRC. AYRS Member Gene Manghi first wrote with the suggestion that the AYRS establish a SYRC in the U.S., and his letter was published in our former AYRS-FCCG Newsletter. Once we receive non-profit status it is entirely possible that we can obtain land and buildings donated by the U.S. Government from surplus or abandoned government or military bases. I would think excellent facilities might be available at Cape Canaveral, Florida. The SYRC could have laboratories, shops, test tank, wind tunnel, dorms for visiting AYRS Members, library and act as a Headquarters for AYRS in The Americas as John Morwood and Michael Ellison have suggested. It would make for permanence and continuity. But, an essential ingredient is that we have at least one AYRS Member to be there on a full work week, and he should have secretarial assistance. Does anyone want to step forward and offer to be the Administrator of the AYRS SYRC?
9. DESIGN CONTEST. It has been suggested that AYRS sponsor same. Do I hear someone volunteer to coordinate this and get it off the ground?

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YACHT RESEARCH, SCIENCE & TECHNOLOGY

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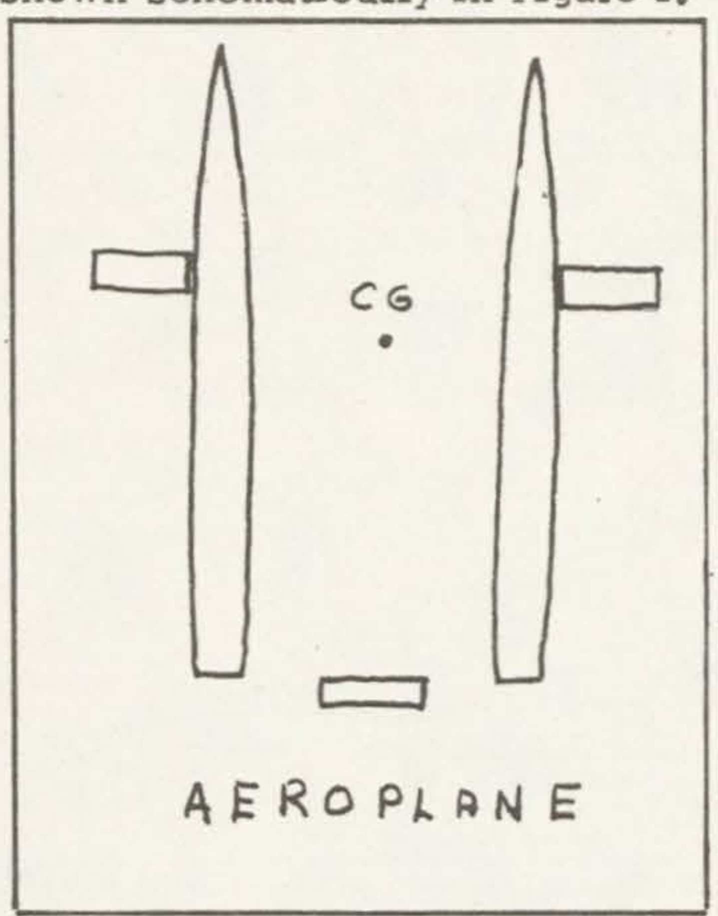
THE APPLICATION OF HYDROFOILS TO SAILING CRAFT - Part III.

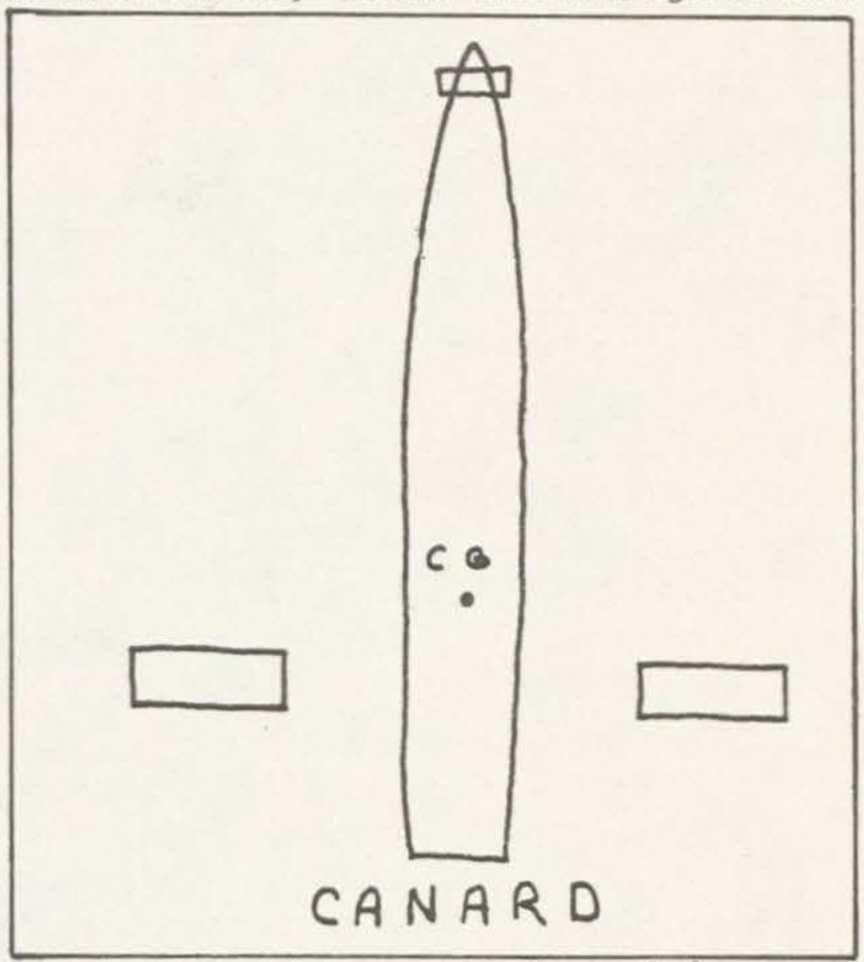
By Joseph Norwood, Jr.; 1021 Valencia Ave.; Coral Gables, Florida 33134.

In this note I would like to address the question of the configuration into which hydrofoils should be arranged on a sailing boat. This is a complex question and cannot be settled without considering the design of the yacht as a whole. Yachts are required at various times and in various combinations to: (1) afford comfortable accomodations, (2) be fast on all points of sail and especially be capable of a high speed made good to windward and downwind, (3) be capable of being single-handed, (4) have a seakindly motion, (5) self-steer on all courses; (6) be cheap to build and easy to maintain, (7) be unsinkable, (8) maneuver crisply under sail in tight places, and (9) have good brakes (yes, that's right, brakes). Any ocean cruising man has found himself in a yacht that was deficient in more than one of these virtues and has suffered accordingly.

A hydrofoil system on a sailing boat must establish a dynamic equilibrium that is stable against roll, pitch, and yaw perturbations (self-steering), in which the boat is raised above the surface of the water, and remains in a level attitude, ignoring small waves and contouring large ones. It is evident that the array of hydrofoils must have considerable extent in both the transverse and longitudinal directions, hence the buoyancy for sub-foiling conditions will be provided by a catamaran, trimaran, or proa hull configuration.

The hydrofoil configuration is symmetric about the longitudinal centerline when applied to a symmetric hull layout such as the trimaran or catamaran. The two simplest configurations in such a case are the aeroplane and canard. These two configurations are shown schematically in Figure 1.





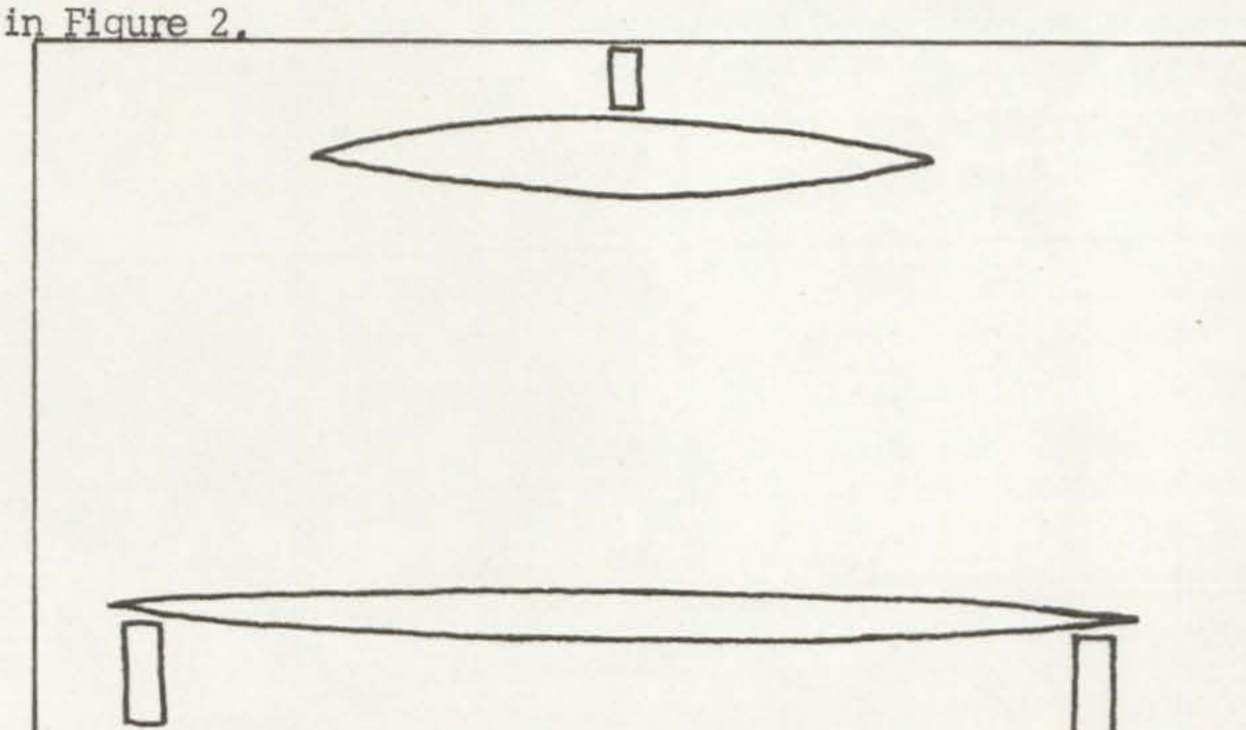
The aeroplane configuration in which the bow foils serve as Bruce foils and the stern foil acts as the pitch stabilizer is shown with a catamaran hull configuration and the canard is shown with a trimaran hull layout. The choice was more or less arbitrary and examples done the other way about could be cited. The main question is one of accomodation requirements. In order to distinguish between these two foil configurations so far as performance capability is concerned, it is necessary to look in detail at the method by which pitch is stabilized.

As we have previously noted, a hydrofoil unit is analogous to a damped spring by virtue of the dependence of its lift on the depth of immersion and angle of attack. The stiffness of the spring is given by the rate of change of lift with depth of immersion, and the damping rate is proportional to the rate of change of lift with angle of attack since vertical velocities are equivalent to a proportional angle change (see Figure 2 in the second paper of this series). If the bow and stern foils have identical characteristics or if the stern foil is stiffer, then a pitching perturbation can lead to a porpoising type of instability. The trick is to use a stiffer foil in the bow and a more highly damped unit in the stern. In practical terms, this calls for a lightly loaded bow foil operated at a higher angle of attack. The stern foil which ideally should carry about 85% of the weight is operated at an angle of attack corresponding to maximum L/D. In a hull-borne craft these characteristics are obtained by using a fine bow with lots of flare above the waterline and a broad flat run off at the stern. For this reason, the canard configuration is expected to be for superior to the aeroplane configuration in pitch control. In lateral roll control (antiheeling) there is not much to choose between the two. If the main foils are both canted lifters (the leeward Bruce configuration) then the angle of leeway will tend to increase the angle of attack of the leeward foil and decrease the angle of attack of the windward foil. Heeling to leeward also serves to nullify the windward foil by lifting some of its area clear of the water. It is unlikely that complete heeling cancellation will be obtained with a symmetric configuration since this would require a very large lateral separation of the foils.

Now let us look at the asymmetric or proa foil configuration. This arrangement has a decided advantage in heeling control since this function can now be concentrated in a leeward Bruce foil arrangement. If a sail plan of modest aspect ratio is used, then the Bruce condition for full heeling cancellation can be met. Since the heeling perturbation induced by the side force of the sail is the largest of the torques experienced by a fast boat hard on its apparent wind, this property of the proa configuration is a powerful recommendation. In a recent paper entitled "Notes on Hydrofoil Heeling Neutralization of Sailing Craft" published in this issue, I showed mathematically that the limit of the effectiveness of a Bruce foil system can be raised appreciably by applying a negative lift on the windward side. This possibility, which exists only for an asymmetric configuration, enables much larger sail area to be carried than would be possible with a symmetric layout.

Pitch control in a proa, owing to the longitudinally symmetrical nature of such craft requires some discussion. In a proa, we assume that the load is concentrated amidships rather than at the stern as in a canard. In order to compensate this, it is necessary to split the Bruce foil into two units located at either end of a long slim leeward hull. This is shown in Figure 2.

ASYMMETRIC
(PROA)

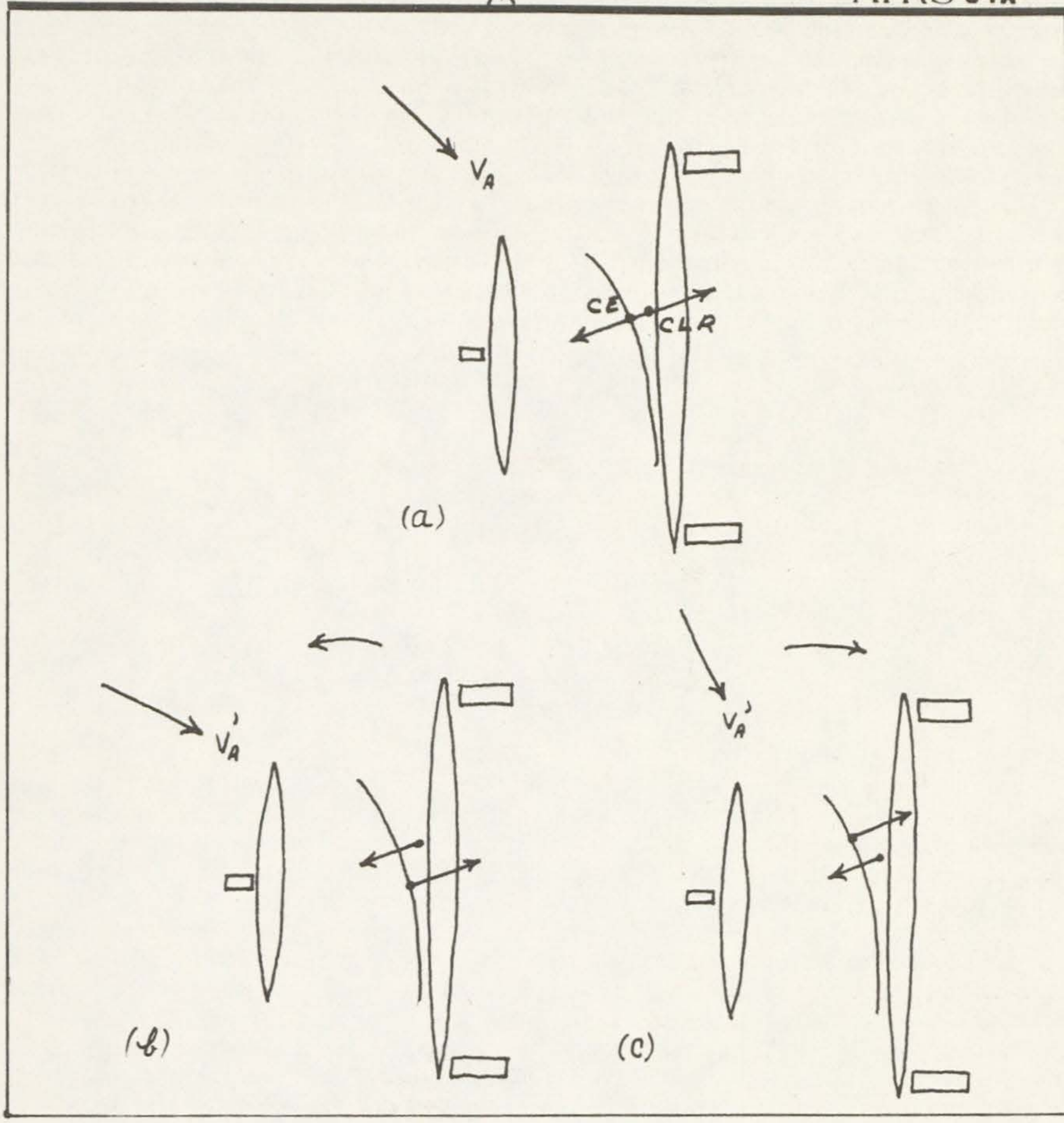


The bow unit can then be operated at a slightly higher angle of attack than the stern foil in order to provide the stiffness and damping arrangement necessary for pitch control. This will have the effect of moving the center of lateral resistance somewhat forward of the longitudinal midpoint owing to the fixed dihedral angle of the foils. This is compensated in windward sailing by the tendency of the center of effort of the sail to move toward the luff.

Finally, let us examine the question of yaw control or inherent self-steering ability. In Figure 3a we show a hydrofoil proa sailing to windward in a balanced condition. If a wind shift occurs such as to increase the angle of attack on the sail, then the CE moves aft and a moment is set up to turn the boat to windward and restore the heading with respect to the apparent wind. Likewise a shift that decreases the course angle will result in a forward shift of the CE, and a torque will arise causing the boat to fall off onto its former course angle. The situation where the true wind suddenly increases in strength without changing direction poses a problem in which

(See Figure 3 at the top of page 7)

the intervention of a helmsman is required. In this case the apparent wind moves ahead as the yacht accelerates even though the direction of the true wind is unchanged. The yacht, by virtue of its tendency to follow the apparent wind, will fall off to leeward in an effort to re-establish its former relationship with the apparent wind and must be corrected by increasing the angle of attack of the bow foil to establish a balance at the higher wind strength. It is possible that this can be done automatically by some sort of mechanical analog feedback system such as that employed by Baker on MONITOR.



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PROATYPE or PROBLEMS OF THE LEEWARD CANTED BRUCE FOIL. By Henry A Morss, Jr.

PROATYPE was not altogether a success as a boat: she was a great success as a teacher and as an experiment. She was intended as a step toward sailing at relatively high speed.

<u>FAST SAILING</u>.

People agree on light weight but differ on other ways to get greatest sailboat speed. Presumably the answer is one or a combination of the following: 1) A craft like CROSSBOW; 2) A flying hydrofoil boat; 3) A planing boat; 4) A "skimmer"; 5) A Bruce foil boat.

CROSSBOW, the present record holder, has a very slender main hull, a big sail rig, and human ballast on a long arm. Every device is used to reduce weight, including the limitation of sailing ability to one tack.

Many people have been trying flying hydrofoil boats for a long time. The first really fast one was Baker's MONITOR (her best reported speed exceeded the present world record). Nigg, Hook, Grogono, Keiper, Chapman and many another have given them a whirl.

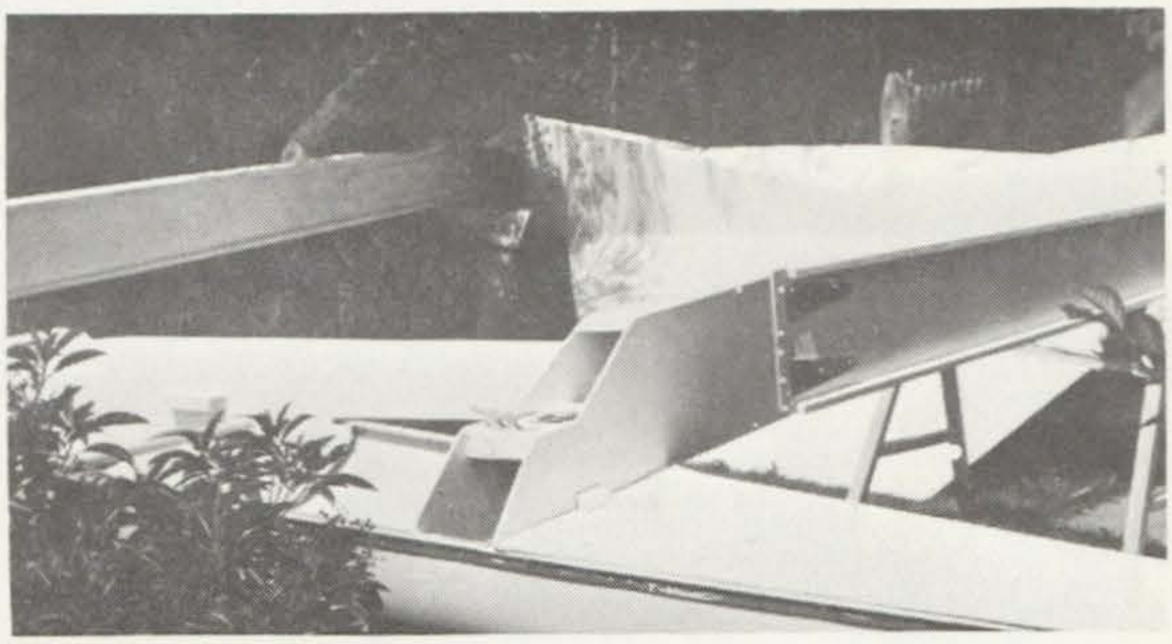
Planing boats can be faster than ordinary non-planing boats, but hardly seem capable of the highest speeds. No one is betting on them. This approach may ultimately prove useful in combination with others.

For the ten square meter size, Prof. Jerry Wolf of the Aviation Institute in Warsaw believes that a very light "skimmer" with a wing-like or kite-like sail may prove fastest when the difficult problems of stability and control have been worked out. (See picture on cover of AYRS AIRS 2.)

Edmond Bruce believed that a "non-heeling" type of craft, now often known as a Bruce Foil boat, would excel because it got its neutralization of heeling and some reduction of displacement from the side force of the sail without robbing the forward driving force.

PROATYPE.

PROATYPE was planned, largely in conformance with Edmond Bruce's own thoughts to investigate further this last possibility. She had as main hull a light, long, slender canoe. To this was attached a 45 degree canted foil of ample area by a pair of hinged arms in a "pantograph." Two identical sails of about 100 square feet each were provided. (See photos, front cover and below.)



NON-HEELING.

Edmond Bruce, in his celebrated article "Opinions about Hydrofoils" in AYRS 51, April 1965, and also AYRS 82, page 226; was the first to introduce most AYRS Members (including myself) to the idea that a sail boat could be made non-heeling. He showed how it was done with a canted foil on a long arm, drew out the accompanying problems of balance, and noted the effects on displacement and on steering.

The effect of fore-and-aft trim seems not to have been discussed previously. A study of this reveals the possibility of counteracting or neutralizing the tendency of the sail force to depress the bow. This can be highly valuable for multi-hulls, many of which have been limited in strong winds by the fear of pitch-poling.

The non-heeling boat has been proven many times in the intervening years but has not yet been exploited fully. PROATYPE was a step in its further exploitation.

"Exploitation" means capitalizing on three features of the non-heeling principle: 1) Sail-carrying Capacity. A non-heeling boat should be able to carry a very large sail area. That means power and speed. It is a kind of thing which is not possible with an ordinary boat. 2) Greater Power when the sail stands up straight. A heeled sail produces less force by a factor of the square of the cosine of the angle of heel. The non-heeling boat avoids this loss. 3) Reduction of Displacement. If a canted-foil craft is sailed with its foil to leeward, the force on that foil has a component directed vertically upward. This reduces effective displacement - another way to increase speed.

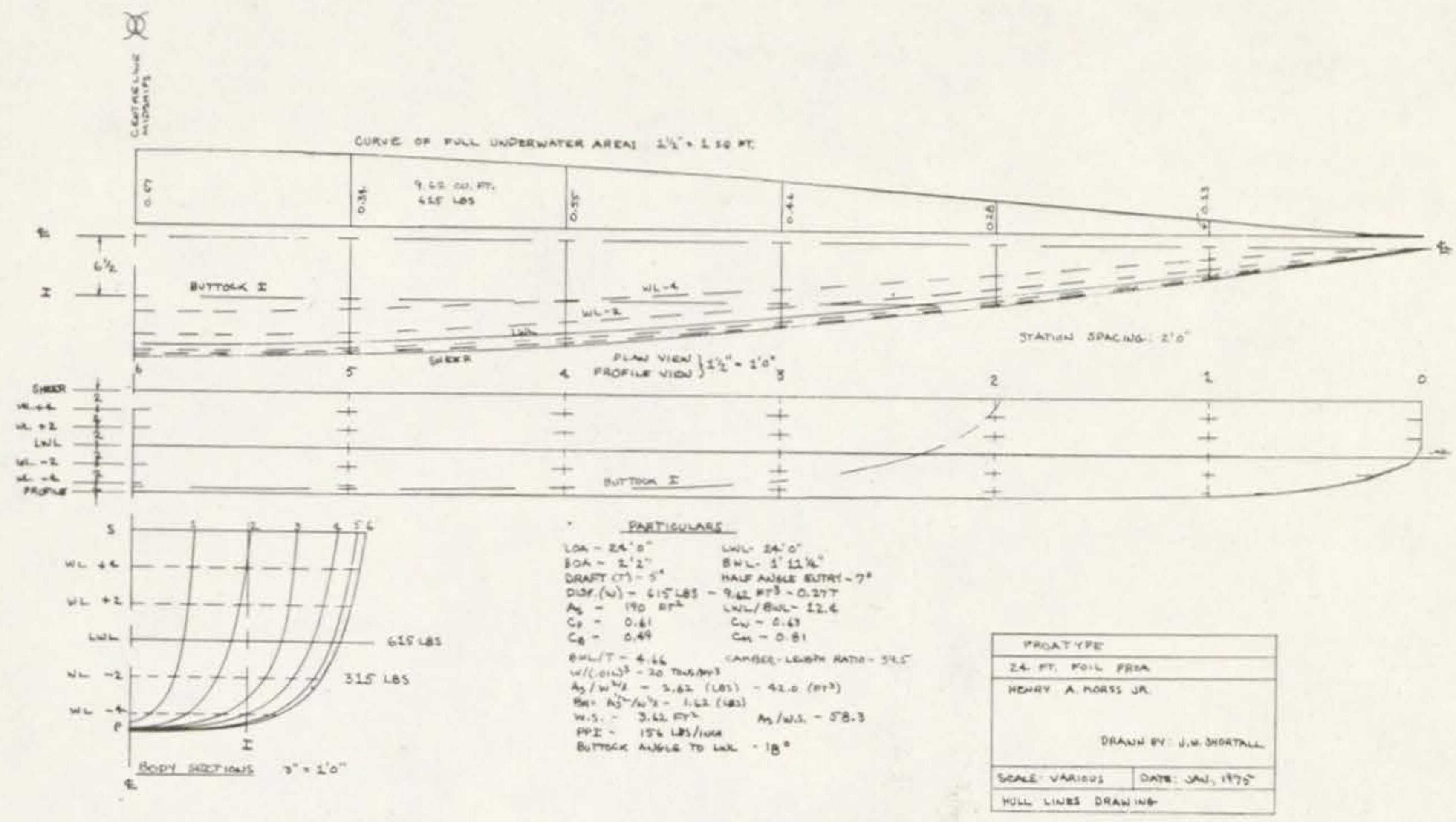
THE DESIGN.

The several photographs give a good idea of the plan of PROATYPE. In detail:

The Main Hull is a stock model racing canoe twenty-four feet long by two feet two inches wide, and very shallow. Length-to-beam ratio at waterline is about 12. The total weight of PROATYPE (see below) is less than half the scaled-up weight of Edmond Bruce's model with the same L/B ratio in his article "Running Resistance vs Speed of Sailing Multihulls" in AYRS 45, October 1963, (also see AYRS 82, Page 195). In view of this fact and the fairness of the lines, this hull is assumed to have low resistance. (An approximate drawing of the lines, very kindly prepared by J. W. Shortall is given as Figure 1, Page 9.)

As can be seen in the photographs, there are fitted into the canoe three stepping positions for masts along with the points of attachment for the cross arms which hold the outrigger. The actual points of attachment of the arms are about eighteen inches outside the canoe itself.

The Arms are of 1/4" plywood, 8 feet long and tapered from 11 to 8 inches in height



with wooden strips glued each side at top and bottom edges to form an I-Section. They are hinged at the ends.

The Single Outrigger is primarily a large "foil" of 3/4 inch plywood with buoyancy at the top as shown in Figure 2 and the photographs. (See Drawings, Page 10.)

Foil Area. To many people the area of the foil will seem excessive. The calculation for it was based on Edmond Bruce's latest thinking. To avoid wave-making and ventilation, he required that the side force carried on the foil should not exceed 70% of the hydrostatic force on one side of the foil.

This foil is sloped at 45 degrees. Its vertical depth below the waterline is two feet. Its width in its own plane below the waterline is 2.83 feet (2 feet, 10 inches), which is 2 / sin 45 . It is eight feet long at the waterline and four feet long at the bottom with somewhat rounded bottom corners.

By Edmond Bruce's rule this foil should be able to support a side force of about 480 pounds. For total sail area of about 200 square feet this would be reached in an apparent wind of about 25 knots or a true wind in the range of 15 to 18 knots.

The Overall Assembly is disgrammed in Figure 3. The length of the arms was figured exactly to neutralize heeling. For this it was assemed that the center of gravity of the whole thing was on the center line of the canoe. Crew on seats just over the windward rail of the canoe pretty well counterbalanced the weights of foil, arms, etc.

Sails and Spars. Two identical "Force Five" boat rigs were provided. The mast is unstayed and "bendy" to support a sail of about 100 square feet. Three mast step positions permit the use of one of these rigs, with mast in center of canoe, or both, with one mast at each cross arm. This made it possible to run the first trials with reduced sail area.

Weights were about as follows: 1) Bare Canoe, 60 pounds. 2) Structure to support masts and connect to cross beams, 40 lbs. 3) Seats, 20 lbs. 4) Cross Beams, 25 lbs. 5) Outrigger, 65 lbs. 6) Two rigs complete with sails, lines, blocks; 60 lbs. 7) Miscellaneous, 30 lbs. This total for boat is 300 pounds. Adding crew weight of 310 lbs. brings the total sailing weight to 610 pounds.

Bruce Number. The sail area to weight ratio $\sqrt{A_S} / \sqrt[3]{W}$ is a little below 1.7. This is slightly lower than those of modern C-class catamarans, whose values are in the range of 1.8 to 1.9.

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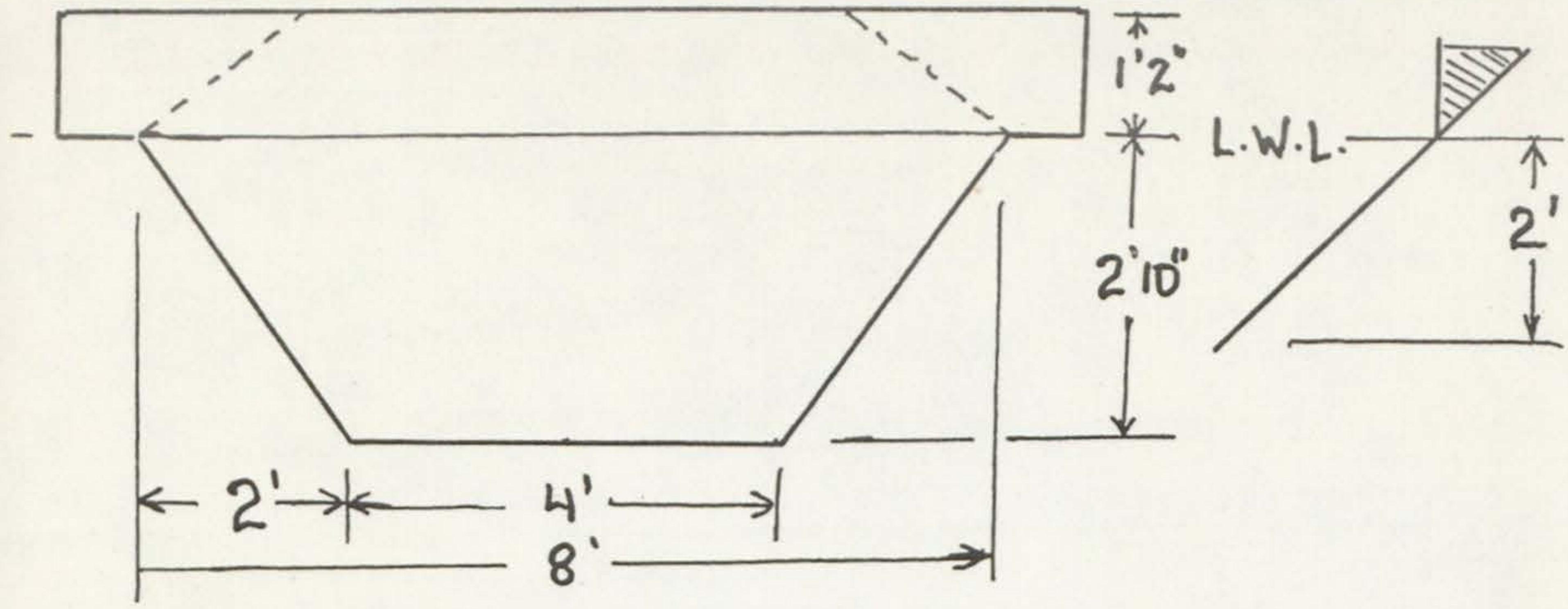
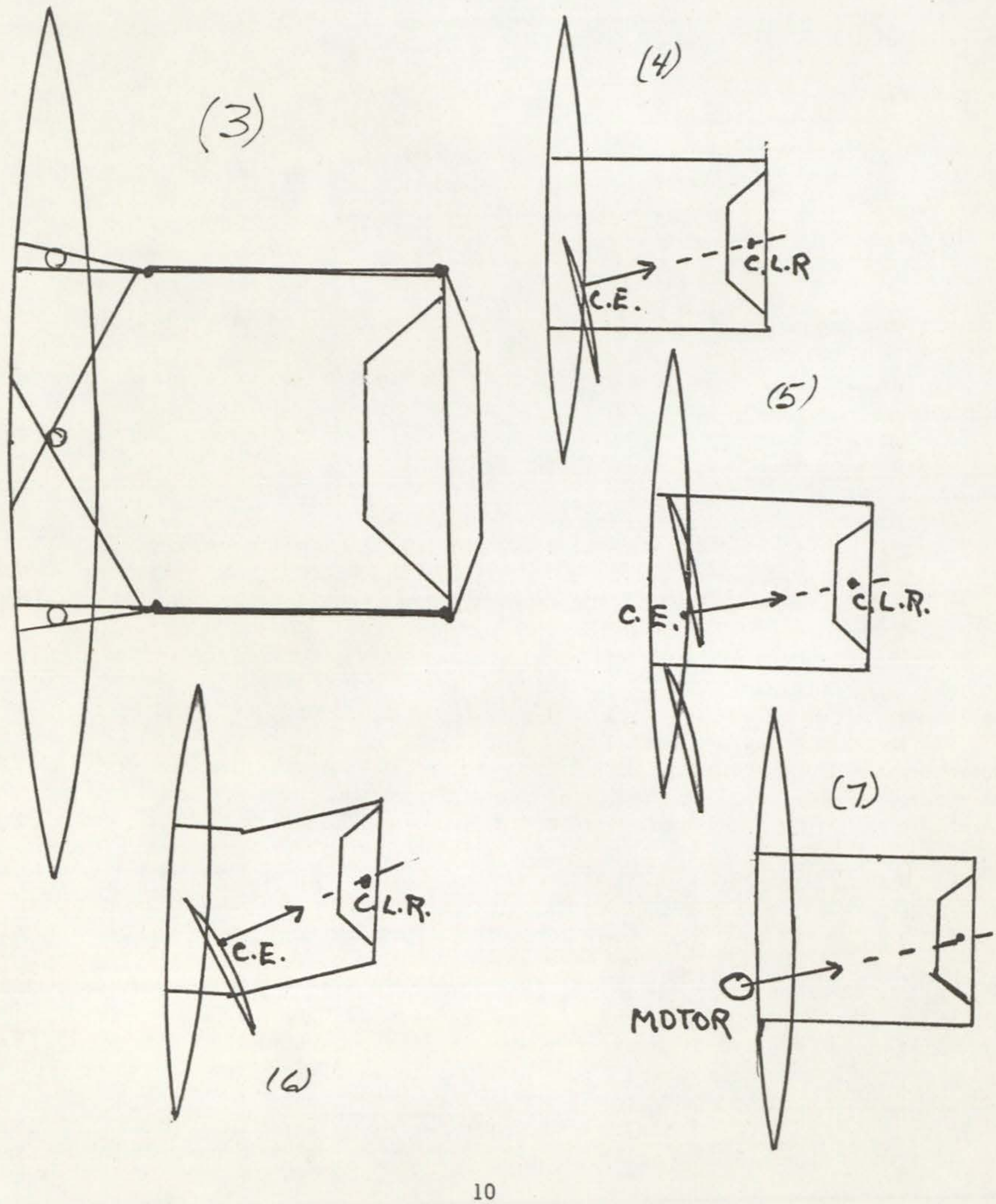


FIG. 2 – VIEW PERPENDICULAR TO FOIL PLANE



THE THEORY OF THE DESIGN.

With speed as a major objective, requirements were: 1) A light hull with low resistance to forward motion at all speeds. 2) Foil designed to avoid wave-making and ventilation. Minimum weight.

Because a foil consistent with the needs is large and relatively heavy, the desire to minimize weight dictated the use of just one foil. The non-heeling principle shows the foil must be always to leeward to get the reduction in effective displacement and consequent reduction in resistance. All this leads to a proa with one outrigger to leeward. (Most proas of the South Pacific keep their outriggers to windward.)

BALANCE AND STEERING.

Before PROATYPE was built, balance and steering were expected to be the most important things to be studied and very likely the principal problems. The theory was clear enough. Its application to our proa requires a substantial fore-and-aft movement of rig or foil to give balance on the two "shunts." This is indicated in Figure 4 with centered foil and the required movement of the rig by "turning it around." This is only an illustration. If it would suffice at all, it would work on only one heading relative to the apparent wind (on each shunt).

Figure 4 shows a single sail, one of the options for PROATYPE. Figure 5 is the similar situation with two identical rigs, both turned around on shunting. On each shunt the center of effort is in the same fore-and-aft position as that of the single rig. Thus the balancing problem for the PROATYPE is essentially the same whether one rig is used or two.

Figure 6 is a modification of Figure 4 in which the sailing angle is a little wider and the boom is not quite so close. The direction of the sail force is further forward. The foil has to move forward to the point where its center of lateral resistance lies on the new line of the sail force. That is the condition for balance on any point of sailing and illustrates the need for the pantograph to permit motion of the foil.

Steering is no more nor less than holding balance or deliberately altering it to cause the boat to turn. Thus the pantograph should be able to steer the boat by maintaining or varying the balance as desired by the helmsman. We gambled that this would work and avoided the complications of rudders at both ends (retractable?) and the extra resistance they would produce.

PERFORMANCE.

Afloat, Idle. One might expect that this craft would be very stable and insensitive to moderate waves on the surface of the water. She is - as unlike an ordinary canoe in this respect as could be imagined.

Under Power. The very first trial of the boat in the water was not under sail but driven by a small outboard motor clamped to the "windward" side of the canoe approximately in the fore-and-aft location of the center of effort of the rig. The motor was turned to roughly 70 degrees from the centerline of the canoe. (See Figure 7). This arrangement produced a driving force quite comparable to that of the sails in every respect except that the force was applied below the waterline rather than nine feet or so above it. The difference was not important because the motor had to be limited to dead slow speed. I was afraid of breaking the unreinforced side of the canoe.

The results of this test were satisfactory in showing that the pantograph arrangement of the outrigger provided adequate steering and control.

Under Tow. The trials were run in Marblehead Harbor, which is a very crowded anchorage. To have room to maneuver a novel and unfamiliar craft, it was necessary to move her to the mouth of the harbor. The obvious thing was to tow PROATYPE with the dinghy driven by the outboard motor. This proved to be very difficult to manage. Steering was poor.

The solution was to put the dinghy alongside the canoe at the stern on the side opposite to the outrigger and to "push". With that assembly, the whole thing could be steered and controlled nicely by the motor.

"Sea Anchor". By far the most conspicuous element of the performance of the craft under sail was her tendency to get into a position with the outrigger to windward. It acted like a sea anchor. While this had been expected, the persistence of it and the difficulty of getting out of this situation had not been anticipated sufficiently.

As is well known, the canted-foil boat will "work" with the foil either to leeward or to windward. It was known that steering would be stable and easy with the foil to windward, possibly unstable with the foil to leeward.

Sailing with foil to windward was not available to PROATYPE because with her arrangement there was no possibility of achieving anything close to balance. Thus it was not possible to resort to the obvious device of getting her going well with the foil to windward, then simply turning her around.

Sailing. When she was made to sail as planned, she accelerated rapidly and was a fast and powerful sailing craft.

Balance. The pantograph arrangement of the outrigger did make it possible to establish balance, as expected. The the sail trimmed in for close reaching, the foil was close to amidships at balance.

Steering. The pantograph also made steering possible. It did not make it very practical. In the limited amount of sailing which was done, the steering did not seem to be sensitive. Control was not easily established or maintained.

With a single sail set, this problem was not too severe. With two, it was. Indeed, control never was established when the full sail area was used. The boat moved quite fast; things happened very quickly; always very soon the boat was heading up into the wind or off before it and swinging to the position with the foil to windward.

Burying. The tendency to bury the bows was strong. This had, of course, been anticipated. The degree of it in even quite moderate wind suggested that significant steps would be taken to correct this. More buoyancy at the ends of the main hull would help. Buoyancy at the ends of the outrigger is not desirable because to minimize resistance the buoyancy above the foil should always be out of the water during sailing. Mostly this buoyancy was in face above water at such times.

Speeds were not measured. The sailing, mostly close reaching, was in winds estimated at four to six knots. Boat speed was probably close to true wind speed.

PROBLEMS.

From these observations, three significant problems seem to need heroic correction: 1) Better steering and control of balance. 2) Means of avoiding or getting away from the "Sea Anchor" situation. 3) Means for preventing or controlling the burying of the burying of the bows.

POSSIBLE SOLUTIONS.

I am tempted with the thought that one major alteration could lead to the solution of all the major problems at the same time. It is to go back to a trimaran with, at first, any conventional rig. To this would be added a retractable canted foil on each side. This could have one novel and perhaps highly valuable advantage to offset its disadvantages.

The disadvantages would lie mostly in the extra weight of the regular outrigger floats of the trimaran (which could be held to minimum size for this application) and in the complications of the retractable foils.

Advantages would be: 1) In ordinary, moderate conditions, the boat could be sailed as an every-day trimaran without the extra foils. There would be no unusual problems in either balance or steering. If some conventional form of centerboard or foil were provided, there would be no reason to employ the retractable foils unless: a) in a good breeze the extra stability of the non-heeling configuration was desired; or, b) the vertical lifting component of the force on the foil was wanted by way of reducing the effective displacement and increasing the speed. These two would tend to go together. 2) The novel feature would be to arrange the craft to utilize the vertical component of the force on the leeward canted foil also to counterbalance the tendency of the bows to bury, the "pitching moment of the sail." (Shortly after writing down this suggestion for the first time, in Sept. 1974, I read Joseph Norwood, Jr.'s similar thought in AYRS-AIRS 8 in his article "Cruising Proas,") Theory says that this can be done. The theory needs to be tested. It can reduce or eliminate the worry about "pitchpoling" in a trimaran. Again the side force of the sail, not the forward driving component of the total sail force, can produce a highly useful effect. It would be difficult to arrange the proa to benefit from this possibility. 3) The choice of a trimaran would have perhaps a significant advantage in compromises it would permit. A leeward canted foil at the normal outer hull but not at the great beam required for full neutralization of heeling would add greatly to the stability, would reduce the effective displacement just as much, and could counterbalance the pitching moment of the sail just as well.

CONCLUSION.

PROATYPE confirmed several aspects of the theory of the non-heeling boat with unexpected emphasis. Edmond Bruce would have like to see that, because he always felt the importance of cross-confirmation between theory and practice before relying heavily on either one.

PROATYPE showed that there was non-heeling, that balance and steering behaved as predicted, and especially that steering was very unstable and difficult when the canted foil was to leeward.

Perhaps its principal contribution was in stimulating more careful thought about possibilities and implications. Out of this came the exciting possibility of neutralizing not only heeling but also the tendency of the sail force to depress the bow. This can be a means of preventing pitch-poling as well as heeling. The future of this idea will be interesting to watch.

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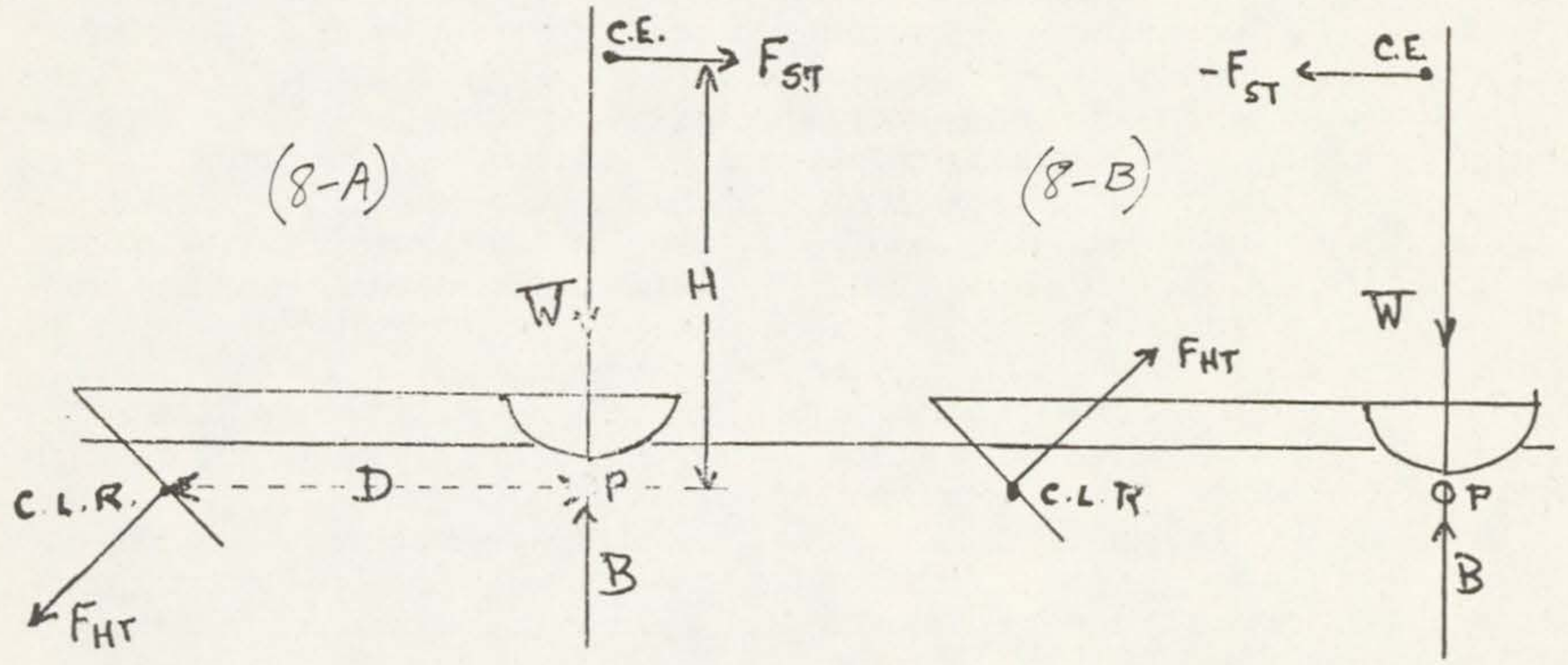
APPENDIX - THE NON-HEELING SAIL BOAT, by Harry Morss.

Reference: "Opinions about Hydrofoils" by Edmond Bruce - AYRS 51, April 1965.

Figure 8, copied from Figure 2 of the reference, contains the principle of the non-heeling sail boat. In simplified form, it shows a boat with a sail and with a canted foil on a long arm, also the projections into a vertical plane perpendicular to the boat's centerline of the principal forces which govern the motion of the boat.

To understand and digest this, one must have in mind the fact that under most ordinary circumstances the force produced by a "foil" moving through a fluid is perpendicular to the plane of the foil, or nearly so. The simplest illustration of this is given in Figure 9-A which shows the cross-section of an airplane wing moving in a fluid. If the wing were symmetrical about a horizontal line and moving in the direction of that line (see Figure 9-B), the total force would be simply a drag force parallel to the motion. When the foil is sloped, relative to the direction of motion (and whether it is symmetrical or not, ordinarily), the force it produces has a "lift" component perpendicular to the motion (by definition of "lift") as well as the drag component. In the typical cases which are of interest for sailing (and flying), the lift component is greater than the drag. The resultant is approximately normal to the plane of the foil, as it has been drawn in Figure 9-A, (See Page 14).



That is the way the forces of sail and foil have been drawn in Figure 8-A. Because of leeway (or "angle of attack," marked a in Figure 9-A), the foil is not moving parallel to its own plane, does produce a lift component and hence a total force normal to its own plane. Figure 8-A pictures the situation when the foil is to windward. The direction of the leeway is such as to produce a force pointing down and to the left, as shown. Figure 8-B for foil to leeward shows the force pointing upward and to the right. In both cases these forces are positioned to oppose the heeling moment. If the foil is put in the right place and at the right angle, it should exactly neutralize the heeling moment.

Toward determination of the conditions for non-heeling, the first step is to adopt

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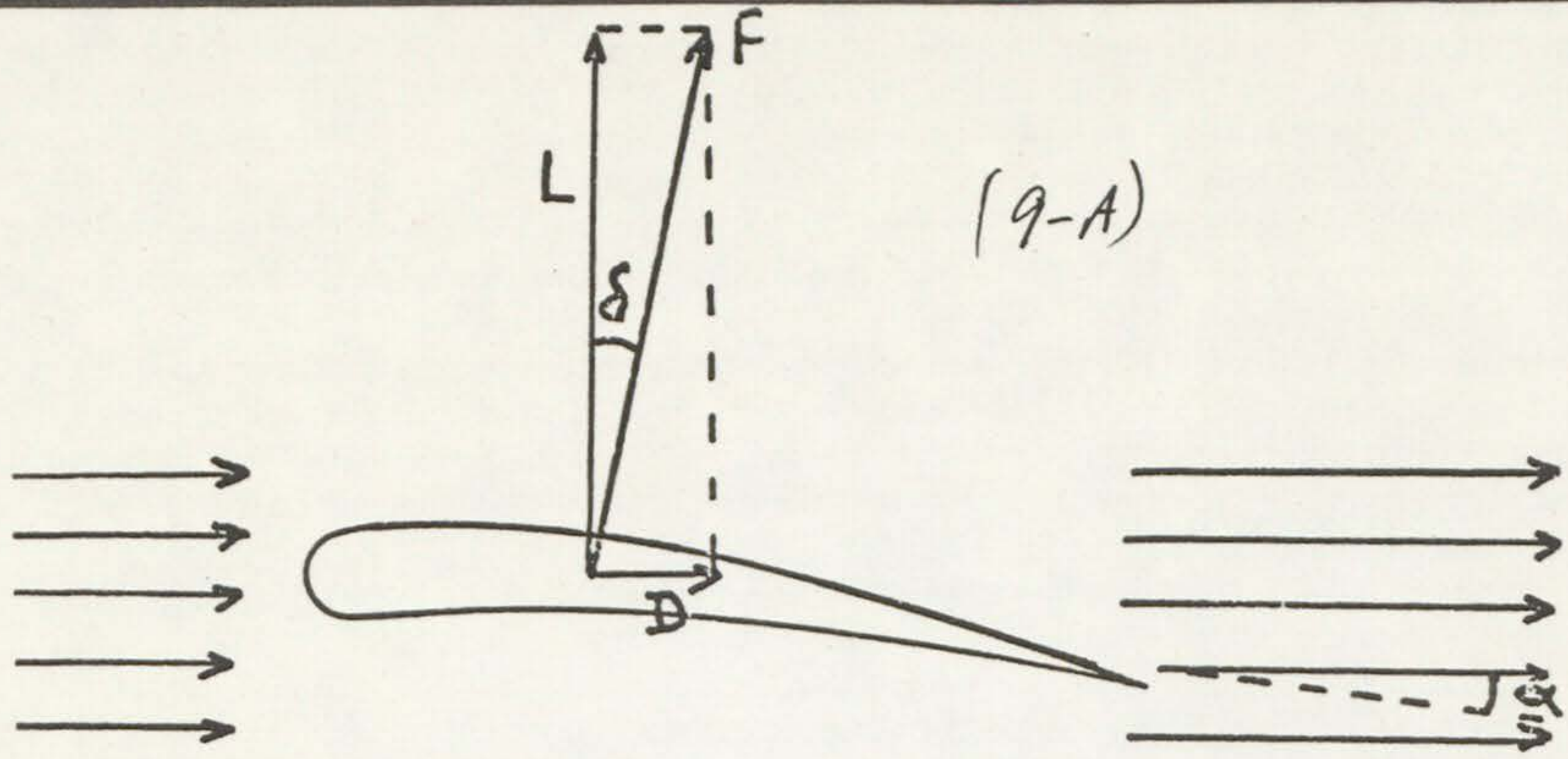


certain simplifying assumptions: 1) The entire force of water on the underbody is carried by the foil, none by the hull, rudder, etc. 2) The center of buoyancy is in the same vertical line as the center of gravity. (If the attitude of the non-heeling boat sailing is the same as its attitude when standing still, this rule must be pretty close to the truth.) 3) The total sail force is horizontal (normal to a vertical sail). Deviations from these assumptions would cause some differences in the details of the following analyses but not in the basic ideas or behavior.

Symbols on the drawings and and in equations and text are defined as follows: B - Buoyancy force; C.E. - Center of effort of sail and parasitic windage; C.G. - Center of Gravity of entire craft, including crew, etc.; C.L.R. - Center of lateral resistance; D - Horizontal distance between C.L.R. and P, (Also "drag" in Figure 9.); D cos θ - Perpendicular distance from line of F_{HT} to P; F - Total or resultant force; F_A - Horizontal component of F_{HT}; F_H - Total hull force or hydrodynamic force; F_{HC} - Component of F_H parallel to centerline of craft; F_{HF} - "Drag" component of F_H, parallel to course; F_{HS} - "Side component" of F_H, perpendicular to course; F_{HT} - Athwartship component of F_H, perpendicular to centerline; F_S - Total force of sail and parasitic windage; F_{SC} - Component of F_S, parallel to centerline; F_{SF} - "Driving component" of F_S, parallel to course; F_{SS} - "Side force" component of F_S, perpendicular to course; F_{ST} - Athwartships component of F_S, perpendicular to centerline; F_V - Vertical component of F_H and F_{HT}; H - Vertical height between C.L.R. and C.E.; J - Horizontal distance between C.L.R. and C.E.; K - Horizontal distance between C.E. and C.G.; L - Vertical distance between C.L.R. and C.G.; (Also "lift" in Figure 9.); P - A point at the level of C.L.R. vertically below C.G.; W - Weight of entire craft, including crew, all gear, etc.; a - Angle of attack; δ - Drag angle; δ_H - Drag angle of hull; λ - Angle of leeway; θ - "Cant angle" of foil, measured from the horizontal.

The athwartships and forward components used mostly here are not the same as the "side," "drag," and "driving" components take perpendicular and parallel to the course for important reasons. These latter are used more commonly.

First Analysis, for Non-Heeling. Figures 10-A and B are separate force diagrams abstracted from Figures 8-A and B. The "heeling moment" about point P is the force component F_{ST} multiplied by the "moment arm" H, the perpendicular distance from the line of F_{ST} to point P, or $F_{ST} \times H$. The moment to oppose heeling is $F_{HT} \times D \cos\theta$. For the complete neutralization of heeling, these two moments, which are opposite in direction about P, (one clockwise, the other counter-clockwise), must be equal, since there are no other moments about P. (In our simplified case, the only other forces are weight W and buoyancy B. Both pass through P, thus have 0 moment arm and produce no moment.) Hence: $F_{ST} \times H = F_{HT} \times D \cos\theta$. By the first assumption above, $F_A = F_{ST}$; and, by trigonometry: $F_A / F_{HT} = \sin\theta$. The combination of these give:

$$F_{ST} \times H = \frac{F_{ST}}{\sin\theta} D \cos\theta; \text{ or, } D = H \tan\theta.$$

This is the condition for the neutralization of heeling. In the particular case of $\theta = 45°$, D = H.

It is easily seen that the derivation is similar and the result the same for the cases in Figures 10-A and B. The same condition gives non-heeling whether the foil is to windward or to leeward. (See page 16 for Figures 9-B and 10 A and B.)

Note the following: 1) A simple statement in words for the condition of non-heeling is that the line of the force on the foil (normal to it through its C.L.R.) must intersect the vertical through the center of buoyancy at the height of the center of effort of the sail. 2) The center of effort of the sail need not be at that point. The rig can be moved laterally without affecting the heeling moment. (Any effect of such movement on the position of the center of gravity of the whole craft must be taken into account, of course.) 3) A very important point about this is that the force which counteracts heeling is derived from the athwartships component of the sail force, not from its driving component. Thus the full driving component remains available to drive the boat. This is quite different from the way it works on flying hydrofoil boats, for instance. 4) In each case F_{HT} has a vertical component. For practical purposes this vertical component may be thought of as increasing the effective displacement of the whole craft if the foil is to windward or decreasing it, if to leeward. When the foil is canted at 45 and is carrying the entire force on the un derbody, the magnitude of the increase or decrease in displacement is equal to the athwartships force of the sail. In a good breeze this can be a significant change in displacement and may cause a change in resistance and speed. 5) The effect of varying the cant angle can be deduced from the equation $D = H \tan \theta$. When $\theta = 45$, $D = H$ and the vertical component of the hull force is equal in magnitude to the athwartships component of the sail force. If θ is increased, the beam will increase and the vertical force component decrease. at 60, D will be up to 1.73H and the vertical force component down to $0.58F_{ST}$. Most people would hesitate to go below, or much below, 45 in this application for fear of excessive leeway. Some day it should be tested. A reduction of just 5 to 40 would decrease D to 0.84H and increase the vertical force component almost to $1.2F_{ST}$.

The Second Analysis, for sail balance, is made in the horizontal plane, with the horizontal projections of the forces shown. Only the hull and sail forces appear. Weight and buoyancy have no horizontal components.

Figures 11-A and B correspond to 8-A and B. The problem here is the sailing or

(Figures 9-B, 10 A and B, and 11 A and B, are on page 16.)

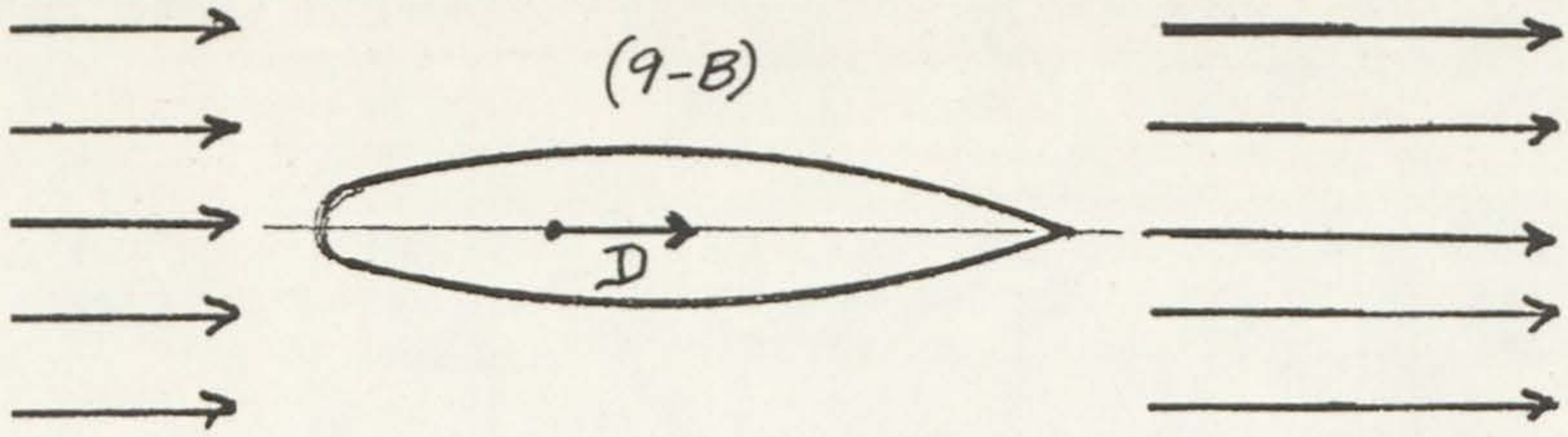
steering balance. The condition for this balance always is that these components be equal and opposite and in the same line when the boat is moving in a straight line without acceleration or deceleration. The condition requires that the C.L.R. or the underbody (assumed to be the C.L.R. of the foil) must lie on the line of the sail force. When it does, the leeway angle and speed will adjust themselves to cause the hull force to lie in this line and to be equal (as well as opposite) to the sail force.

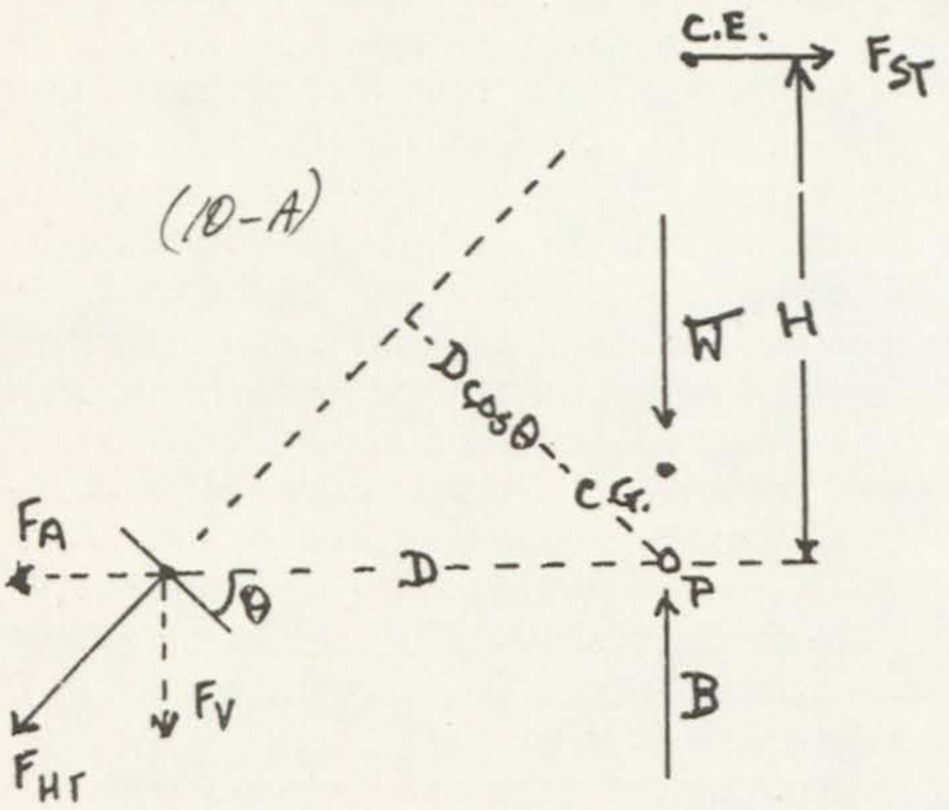
As is seen in 11-A and B, this condition is met only if the foil is further forward when to leeward than when to windward. Somehow this sizable relative movement has to be accomplished by moving either the sail or the foil.

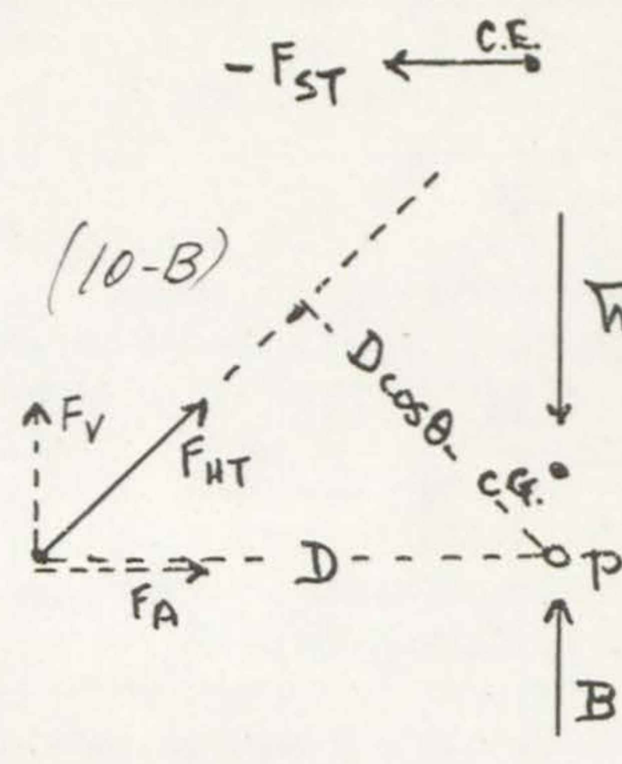
It as another aspect too. As can be seen from Figure 11, the steering is inherently very stable when the foil is to windward and unstable when it is to leeward. This is further emphasized in Figure 12. In 11-A, the horizontal projections of the sail and hull forces, F_S and F_H, are in the same line. Balance is achieved. In 12-A, the boat has turned a bit and thrown the forces out of line. The forces will tend to realign themselves. Perhaps the best way to be sure of this is to think of point C.L.R. as a fulcrum or pivot around which the boat can swing. (We have assumed that all the hull force is carried by the foil.) The force F_A passes through that point still and will not have any turning effect on the boat. Force F_S, on the other hand, will tend to turn the boat in the direction indicated by the curved arrow. This will bring (or try to bring) force F_S back into the line of F_H and restore balance. If the original displacement had been the other way, the turning moment would be opposite to that of the curved arrow. Again balance would be restored.

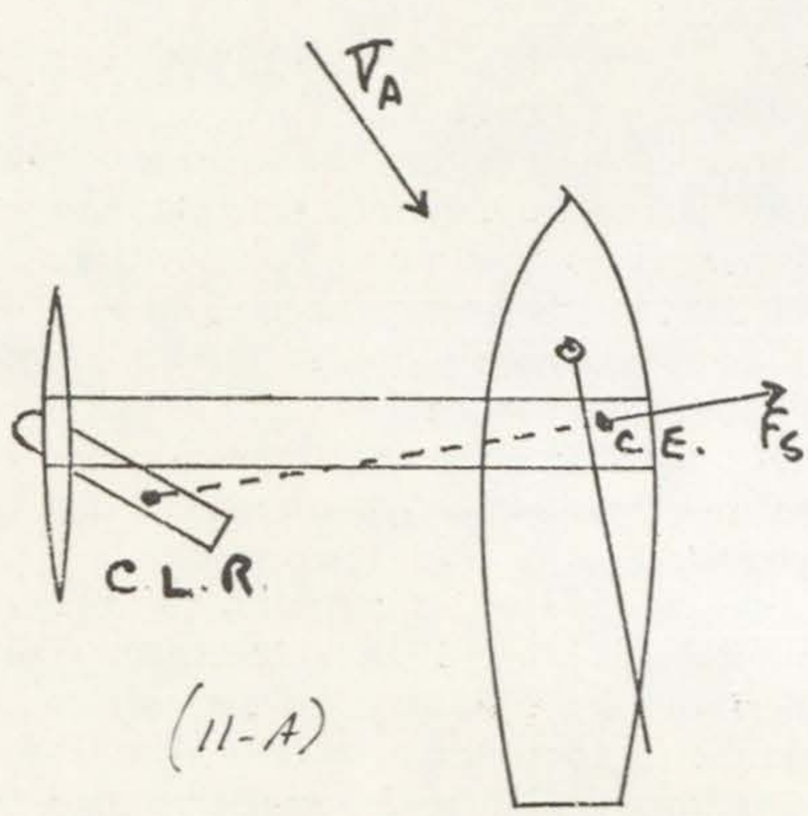
Figures 11-B and 12-B show the very different situation which exists when the foil is to leeward. In 11-B, the boat is in balance. In 12-B is seen the effect of a displacement. This time the turning moment will tend to increase the displacement, as marked by the curved arrow. As the displacement increases, the turning moment increases in strength. Whichever way the original displacement occurs, the tendency is to swing the boat further off course rather than to bring it back, as occurred when the foil was to windward.

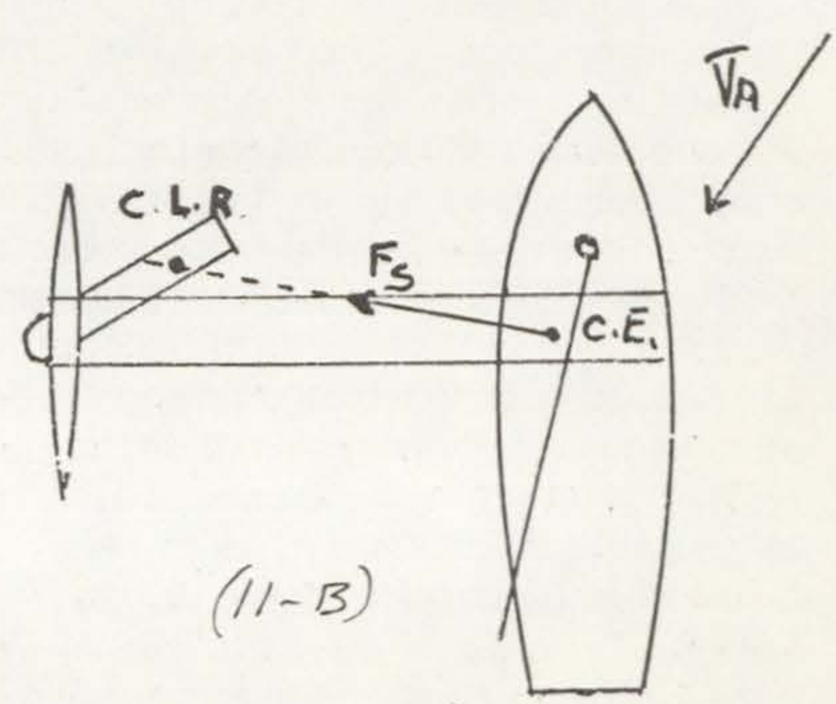
Thus we may think of the steering as being very stable, once balance has been es-







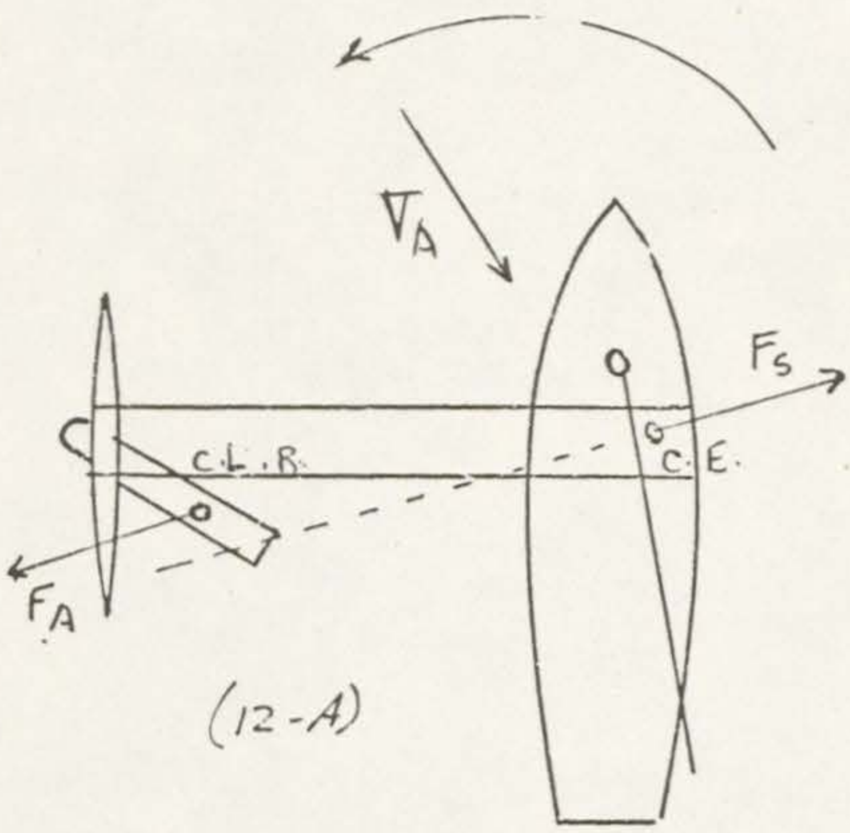




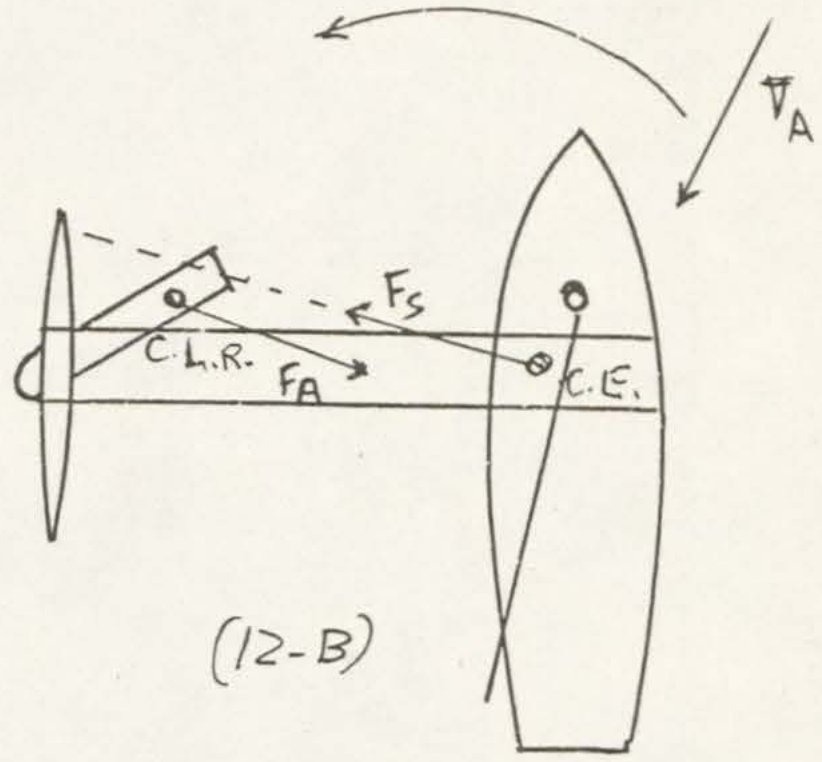
tablished, when the foil is to windward, but rather unstable when it is to leeward.

For purposes of design, one needs to know the amount of relative motion of rig and foil needed to assure balance. For this, Figure 11 has been redrawn with the addition of the course, the hull drag angle, and the angle of leeway, in Figure 13. In both halves of the figure, the angle between an athwartships line and line of the force is $\delta_H - \lambda$. Thus the relative motion needed is 2 D tan $(\delta_H - \lambda)$. This is likely to be much less than one might think if he were to jump to the wrong conclusion and suppose that the angle to use was δ_H rather than $\delta_H - \lambda$. The centerline of the boat, not the course, is the line of reference here. (See Figure 12 on next page.)

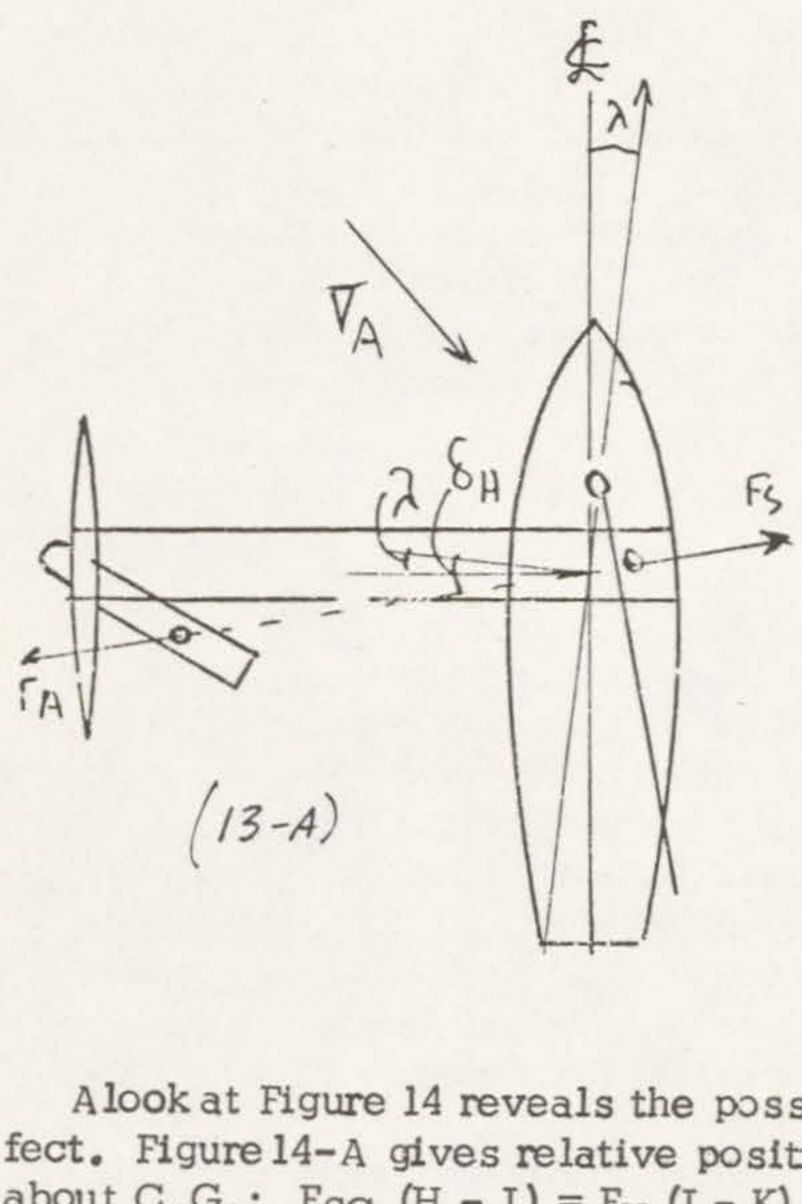
The Third Analysis, for "pitch," can be derived from a projection of the entire non-heeling craft into a plane perpendicular to the two used previously, a fore-and-aft vertical plane. In Figure 14 can be seen the forces which affect "pitch," or the fore-and-aft attitude of the boat. It is, of course, well known and obvious that on any ordinary sailing craft the forward or driving component of the sail force has the effect of depressing the bow or pushing it deeper into the water. Normally this is counteracted by the extra buoyancy of the depressed bow. In many boats, especially heavy ones, the effect is small and seldom even thought of. Sailors of catamarans and trimarans are much more aware of this as a problem. When these boats heel only a little, their leeward hulls are deeper in the water. Often their bows are not far above the surface and the waves. Occasionally in this situation the bow will go under, perhaps in a wave. This can cause pitch-poling. Alert crews move their weight aft.



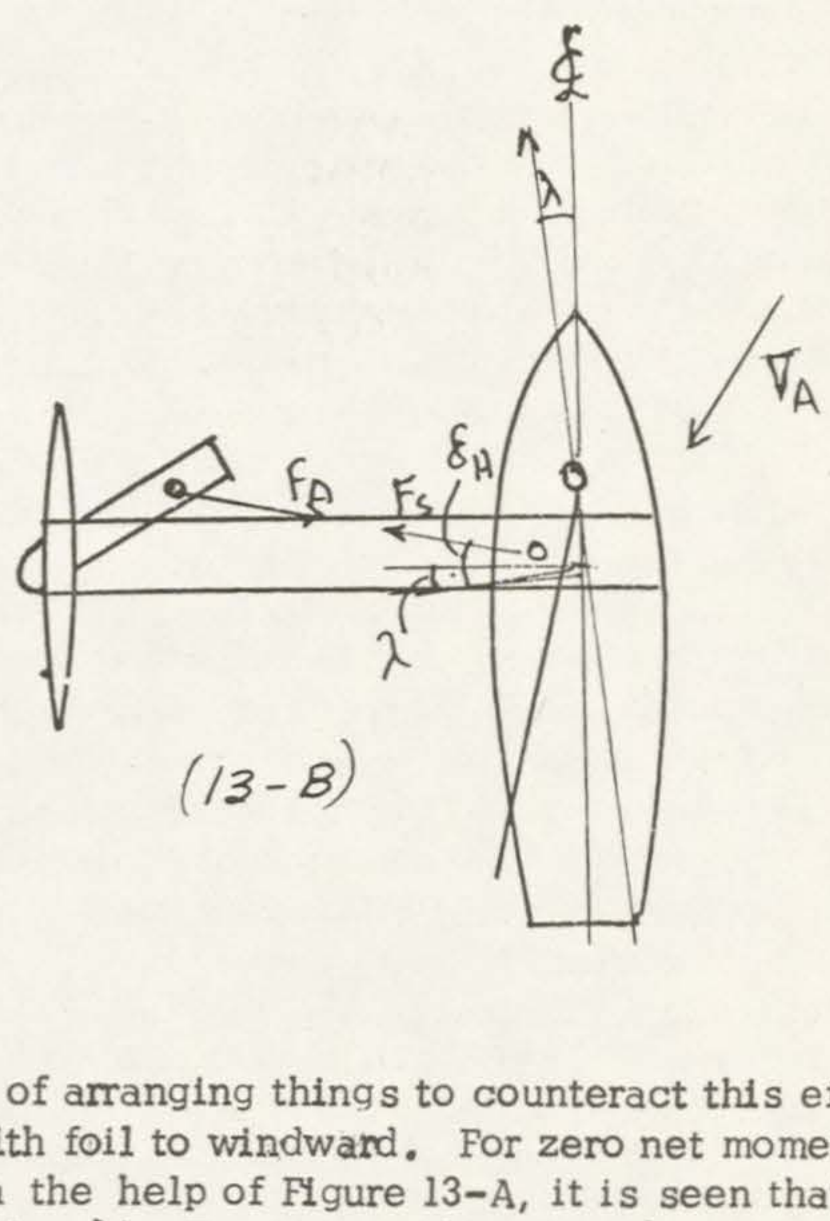
(12-A)



(12-B)

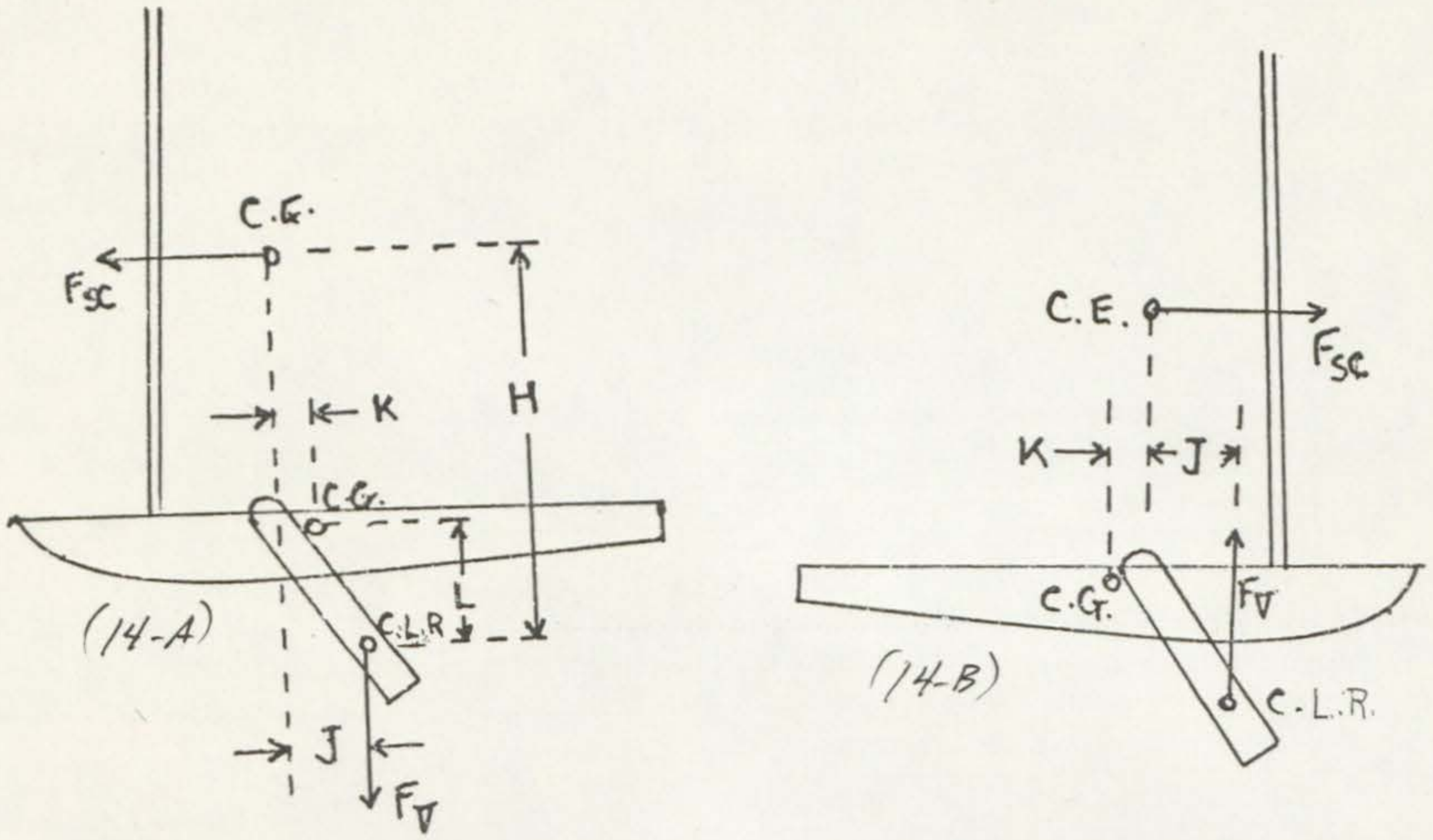


(13-A)



(13-B)

A look at Figure 14 reveals the possibility of arranging things to counteract this effect. Figure 14-A gives relative positions with foil to windward. For zero net moment about C.G.: F_{SC} (H − L) = F_V (J − K). With the help of Figure 13-A, it is seen that: $F_{SC} / F_{ST} + \tan (\delta_H - \lambda)$, or $F_{SC} = F_{ST} \tan (\delta_H - \lambda)$. From Figure 10-A: $F_A/F_V = \tan \theta$, of $F_V = F_A/\tan \theta$. The first of the basic assumptions was that $F_A = F_{ST}$. When these are combined: $(H - L) F_{ST} \tan (\delta_H - \lambda) = (J - K) F_{ST}/\tan \theta$, or $J - K = (H - L) \tan (\delta_H - \lambda) \tan \theta$. This is the answer. To counteract the depressing effect of the sail force on the bow, the C.L.R. of the foil should be located at this distance aft of the center of gravity. This in turn fixes the position of the rig. To see the meaning of simple terms, we note from the "second analysis" that when heeling is neutralized, $J = D \tan(\delta_H - \lambda) = H \tan\theta \tan(\delta_H - \lambda)$. If this is subtracted: $-K = -L \tan\theta \tan(\delta_H - \lambda)$. That is, the C.E. must be this small distance forward of the center of gravity. That it is small comes from the fact that L is obviously small, tan θ may be one or somewhat more if θ = 45 or more, and $\tan(\delta_H - \lambda)$ is of the order of 0.2 if δ_H is about 15° and λ about 5°.



For sailing with the foil to leeward, Figure 14-B is used. Here: $(H - L) F_{SF} = (J + K) F_V$; $J + K = (H - L) \tan\theta \tan(\delta_H - \lambda)$; and, $K = -L \tan\theta \tan(\delta_H - \lambda)$. With the negative sign, the center of effort should be placed aft of the center of gravity by this distance, not forward as indicated in the drawing.

Close-hauled, close-reaching, and beam-reaching. The above estimate of the relative positions of C.E., C.G. and C.R. assumed sailing pretty close by the wind. As the sailing angle increases, $_H$ will also increase and with it the preferred fore-and-aft spacing of the three centers. If C.L.R. is farther from C.G. than required for a given sailing angle, it will lead to overcompensation of the pitching moment of the sail on that course, a tendency to lift the bow. If the rig is moved with it, the non-heeling effect will persist unchanged. As the course widens, the lifting of the bow will gradually disappear. It would be nicer if this worked the other way around. Presumably lifting of the bow is needed more off the wind.

The designer will have to make a choice. He can select the fore-and-aft position of rig and foil independently of the non-heeling consideration to get what he wants of lifting of the bow.

Partial Stabilization of Heeling. At times it is desirable or convenient to go only part way in placing the foil far enough out to the side for neutralization of heeling. One example of this is the use of the canted foil on a catamaran without increasing the beam. Brian King reported such trials in AYRS-AIRS 1. When this is done the full vertical component of the foil force will be realized and the complete neutralization of the depression of the bow can be achieved. For this, the same fore-and-aft positioning of foil relative to the center of gravity would be adopted, and the appropriate position of the rig determined last.

REQUIRED AREA OF SURFACE-PIERCING FOILS. Here are Edmond Bruce's own words describing the method of estimating the area of surface-piercing foils, written in February, 1973.

"Tank tests on surface-piercing foils have revealed a new method for calculating the required submerged area for foils. It may well prove to be the simplest and most accurate method to date.

"No portion of a foil can support a normal pressure which exceeds the hydrostatic pressure, at that point, resulting from depth. If it encounters a greater positive pressure, a wave will pop out of the water surface, thus injuring the effectiveness. A corresponding negative pressure on the lee side will "suck" the water level downward leaving only air in contact. This "ventilation" is even more harmful.

"Tests have shown that, as a factor of safety, one should not attempt more than 70% of the above critical pressure if adequate foil action is expected. This gives us the basis for a good and simple calculation for the minimum area for a foil.

"For example, suppose that a surface-piercing foil has an immersed depth of two feet. Its average depth will be one foot. Since salt water weighs 64 pounds per cubic foot, the average hydrostatic pressure on the foil will by 64 pounds per square foot of area of its vertical projection for one face. Using the above factor of safety of 70%, one gets nearly 45 pounds per square foot for the maximum pressure that can be supported. Thus if, for example, the side force of a sail is 200 pounds, 200/45 = 4.44 square feet of projected vertical plane area is needed for an effective foil. Thus the foil should be, at least, 4.44/2 feet wide, or 2.22 feet.

"In the future, I intend to employ this method since tank experiments fully support this theory."

For PROATYPE, this works out as follows:

a) For the middle four feet of the board, the average depth is one foot, the area in vertical projection is eight square feet, and the total force should not exceed 1 x 45 x 8 = 360.

b) For each end section, the average depth is less than one foot, because the area above that level is three times the area below it. When this is worked as a simple problem in integral calculus, the average depth is found to be 2/3 of a foot. (An approximate method is to take narrow horizontal strips, perhaps each a quarter of a foot deep, figure them separately, and add.) Then the force on each end section should not exceed (3/4) x 45 x 2 = 60.

The total side force, then, should not exceed 360 + (2 x 60) = 480.

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NOTES ON HYDROFOIL HEELING NEUTRALIZATION OF SAILING CRAFT.

By Dr. Joseph Norwood, Jr.

In 1965, Edmond Bruce wrote his celebrated "Opinions About Hydrofoils," article (See AYRS 82 DESIGN FOR FAST SAILING p. 226) which showed the possibilities for neutralizing the heeling torque on sailing craft. Edmond's emphasis in that paper and in his letter to Dr. Feldman (AYRS 82 p. 235) was on applications to dinghies. Certain limitations are evident for high speed craft where the sail force may be of the same order as the total boat weight.

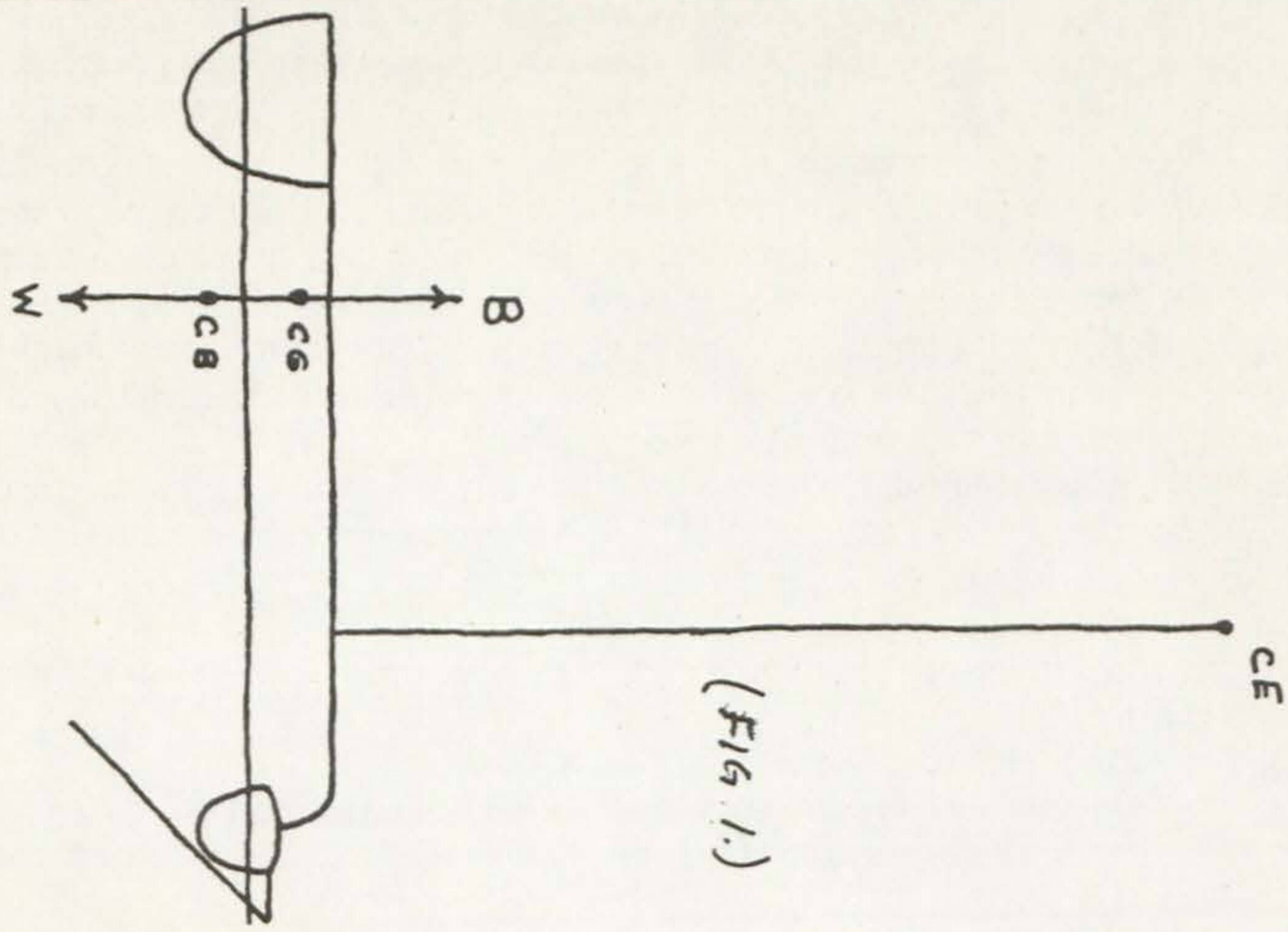
In Figure 1 we show a Bruce foiler at rest. The only forces operative are the gravity force which is canceled by the buoyancy force. Thus the total force is zero and the foiler is in a state of static equilibrium.

(See Figure 1 at top of page 20.)

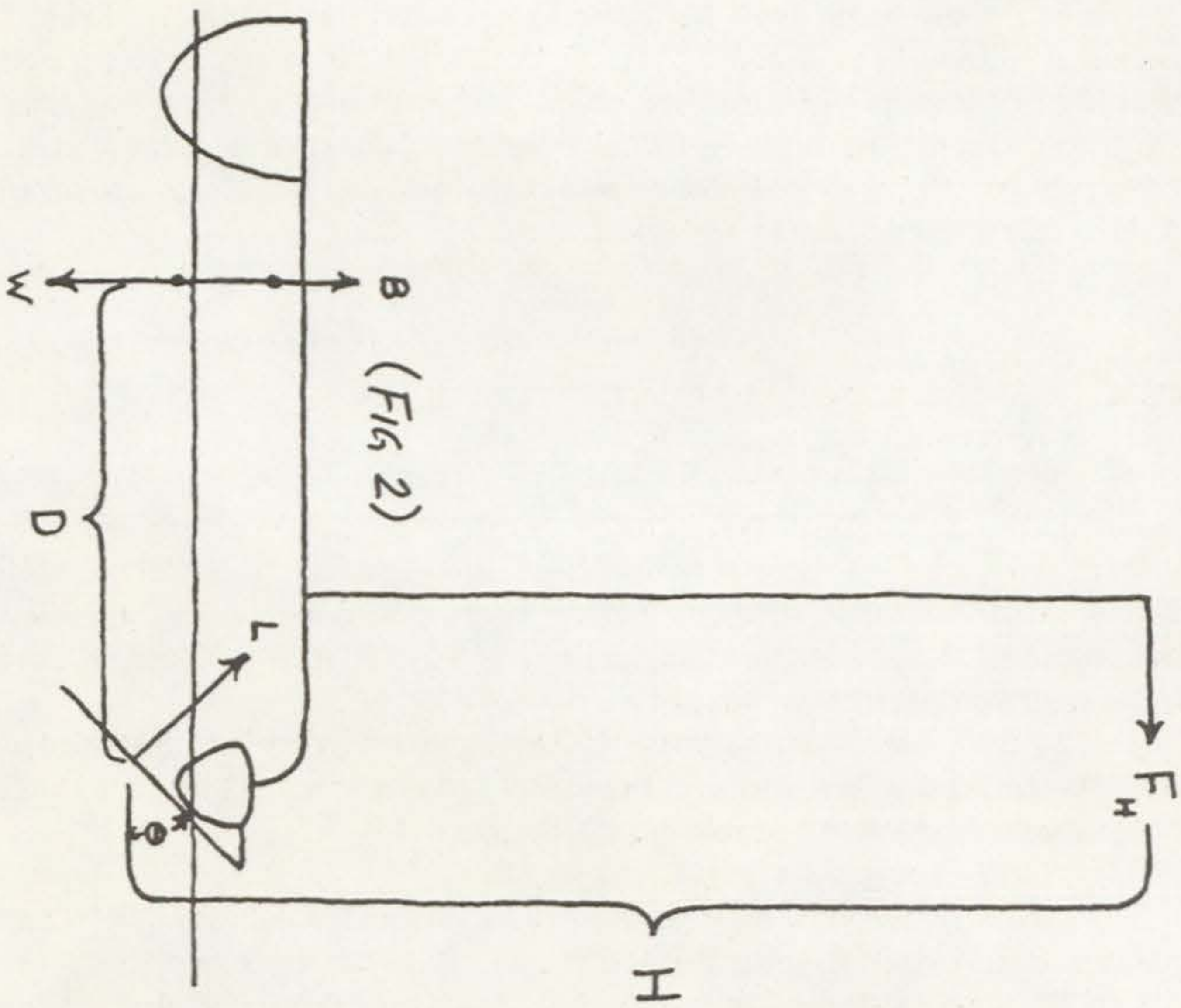
Now we turn our attention to the Bruce foiler in motion. We assume no accelerations, that is, a state of dynamic equilibrium. The forces exerted on the Bruce foiler with its foil to leeward are shown in Fig. 2. The basis for choosing to leave the buoyancy B in the same vertical line as the weight W is the assumption that we will be successful in eliminating the heeling torque. Were this assumption not justified, then the CB must move to leeward as the boat heels.

(See Figure 2 at top of page 20.)

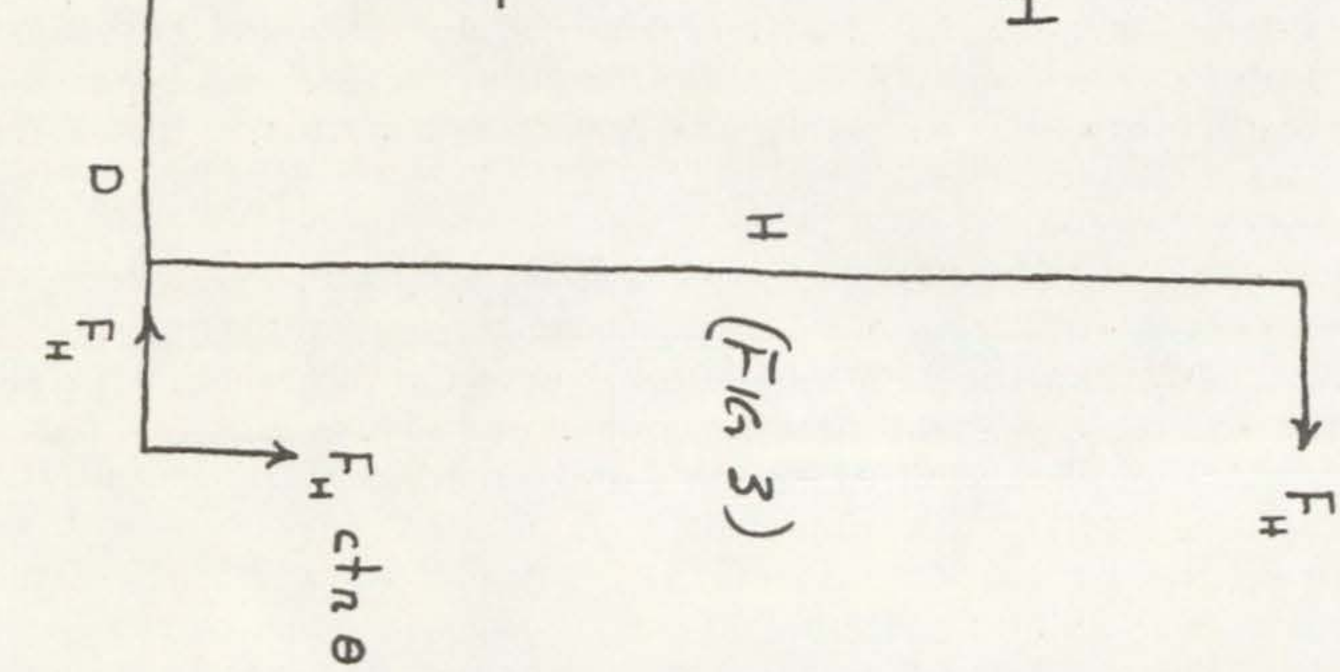
In order to enjoy a state of equilibrium, an extended body must have zero net forces in the vertical and horizontal directions and the moment of the forces (torque) about any point must vanish. (We neglect as not of interest here the forces normal to the page, that is, the thrust and drag.) These first two conditions imply: $B = W - L \cos \theta$, and $F_H = L \sin \theta$. Multiplying Equation (1) by $\sin \theta$ and Equation (2) by $\cos \theta$ (where θ is the dihedral angle of the foil) and adding, we find: $B \sin \theta + F_H \cos \theta = W \sin \theta$, or $F_H = (W - B) \tan \theta$. By virtue of Equation (2), we see that the vertical hydrofoil force is: $L \cos \theta = F_H \operatorname{ctn} \theta$. Using Equation (3), we can express the buoyancy B as follows: $B = W - F_H \operatorname{ctn} \theta$. Thus the Bruce foiler in dynamic equilibrium can be reduced to the force diagram shown in Fig. 3, page 20. Taking moments about any point leads to the following: $F_H (H - D \operatorname{ctn} \theta) = 0$. Since F_H is never zero except in the (trivial) static case, the quantity in parenthesis must vanish in order to ensure the vanishing of the heeling torque. Thus: $D = H \tan \theta$.



(FIG 1.)



(FIG 2)



(FIG 3)

What is the limit to the heeling force that can be tolerated? With Equation (7), in effect F_H can take on any value and Equation (6) will still be satisfied. The conclusion that almost any sail area can be carried in almost any wind would be premature, however. The limitation lies in Equation (3) for the equilibrium of vertical forces. This equation describes the decrease of B, the buoyancy, as F_H increases, thus increasing the vertical lift of the Bruce foil. As F_H approaches W tan θ, the buoyancy approaches zero as the hulls lift out. At this point of liftoff, the force diagram becomes that shown in Figure 4, page 20. The force components F_H ctn θ of the couple have reached a maximum value W; the maximum righting moment is therefore: N_{max} = WD, and any further increase in F_H over: $F_{H,crit.}$ = W tan θ will lead to capsize. If we replace the Bruce foil by a light non-submersible float, the same maximum righting moment is found. The virtue of the leeward Bruce foil is that the heeling force can be converted to reduce the displacement.

Without going through the detailed analysis which is analogous, the Bruce foiler with foil to windward can be summed up as follows:

1) Windward canted foils are unstable. If the foil pops out owing to wave action, over you go.
2) The windward foil depresses the craft rather than raising it, so the limiting value of F_H depends on the reserve buoyancy, that is, when you are dragged under, you have pressed too far. In practical terms, increased wave-making drag and wetted area will set the limit.

The lack of stability and the increase in the wetted area render the Bruce foiler with foil to windward unsuitable, in my estimation, for offshore sailing and I shall not consider it any further.

In order to further increase the tolerable F_H (that is, the sail area), we must follow up a suggestion made by Hugh Barkla. (Barkla, H. The Physics of Sailing, Phys. Soc.) He noted that a fast sailing foiler must be able to absorb forces exceeding its weight and torques exceeding WL, the weight times length. Barkla notes that this can only be done by employing negative lift to hold down the windward side. What is wanted is a foil that would exert no vertical forces until liftoff is reached; the foil, located to windward, should then begin to exert a negative lift that increases in magnitude over a moderate range as the boat raises further. Such a foil is not only possible, it is practical as well and is being developed for use on the writer's proa.

Using the windward foil described above, the force diagram for F_H W tan θ is as shown in Figure 3. For FH = W tan θ, Figure 4 applies. For F_H W Tan θ, the depressing force K to windward turns on and the force diagram shown in Figure 5 applies.

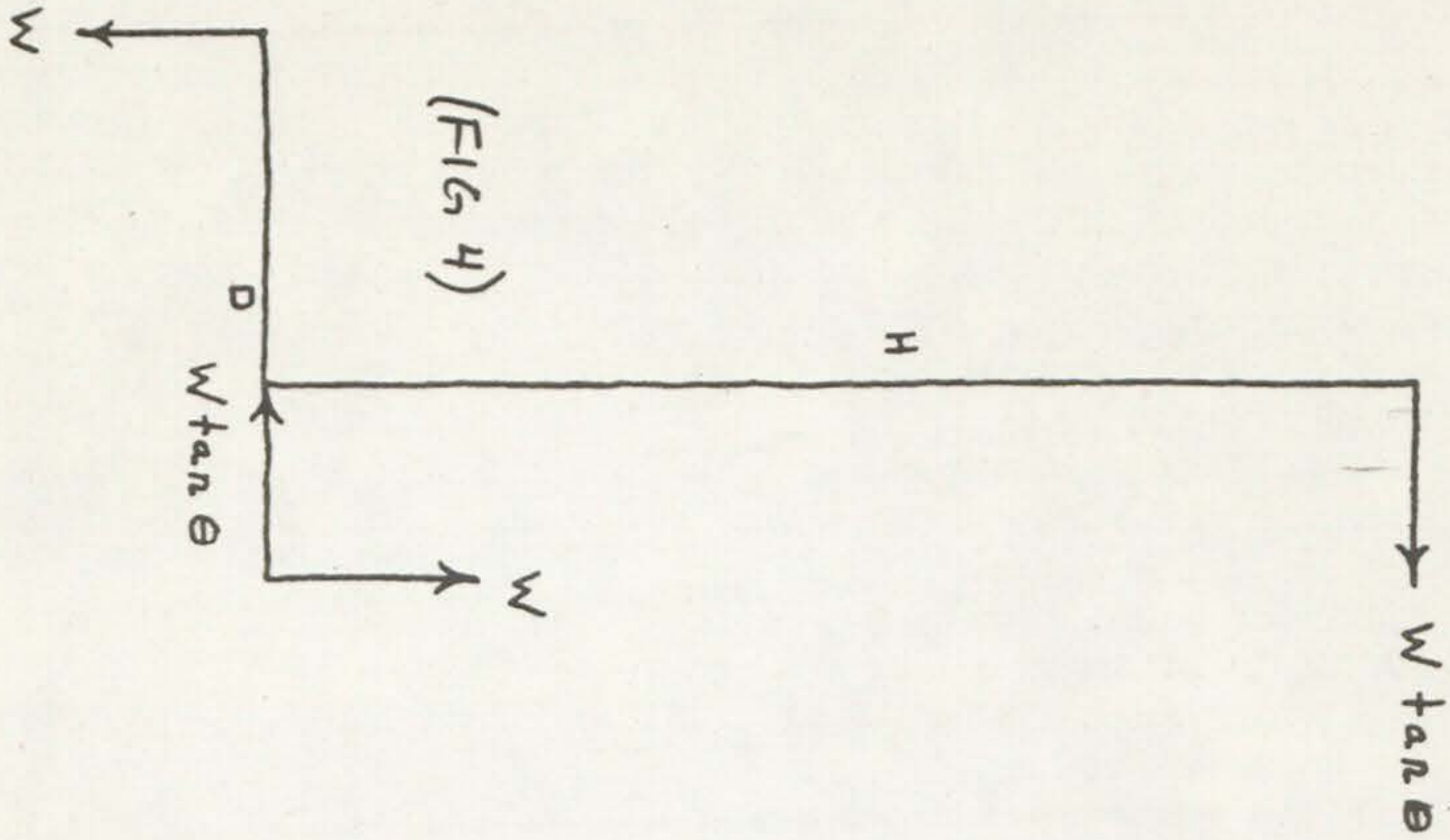
(See Figures 4, 5, and 6 on page 22.)

We see by summing the vertical forces in this diagram that the windward negative lift must vary according to: K = F_H ctn θ - W. Thus, as before, we can eliminate all of the variables except F_H and; using the force diagram shown in Figure 6, the heeling equilibrium condition analogous to Eq. (6) is found to be: $F_H(D' \text{ctn}\theta - H) = W(D' - D)$. The only nontrivial solution of this equation is for both parenthetical expressions to vanish, that is: D = D' = H tan θ. If the lift curve specified by Equation (10) can be met (and it seems likely that it can) then the foil should be located at the center of gravity. From a practical point of view this presents problems since the center of gravity shifts to windward as the load or crew are increased. For this reason the foil will be located on the windward side of the windward hull and its angle of incidence will be tuned to level the boat. This foil will be stable over a sufficient range to a heeling perturbation unlike the windward Bruce foil which is unstable to a perturbation of any magnitude.

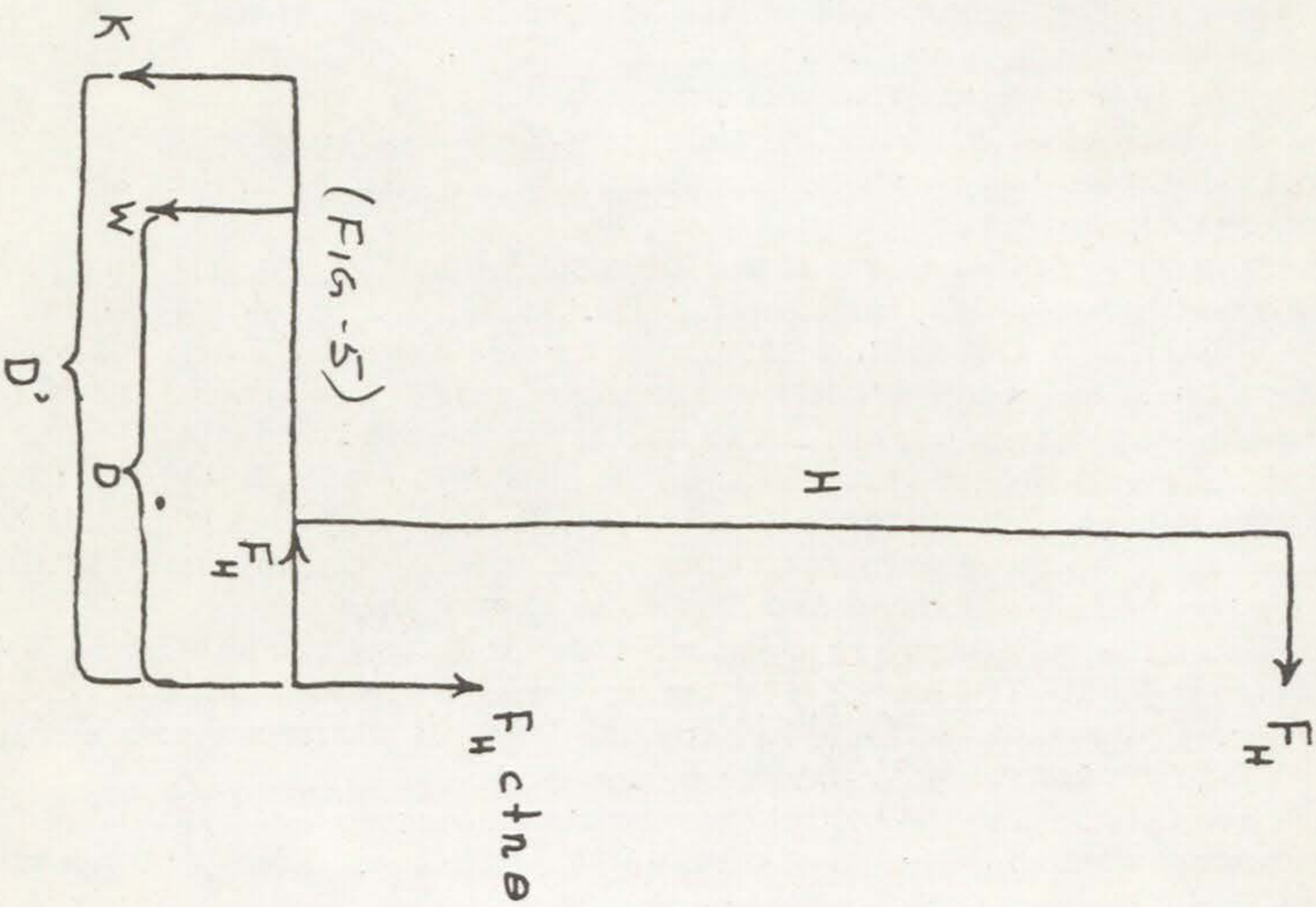
The maximum value of F_H is now determined from Eq. (10) as:

$$F_{Hmax} = (W + K_{max}) \tan \theta,$$

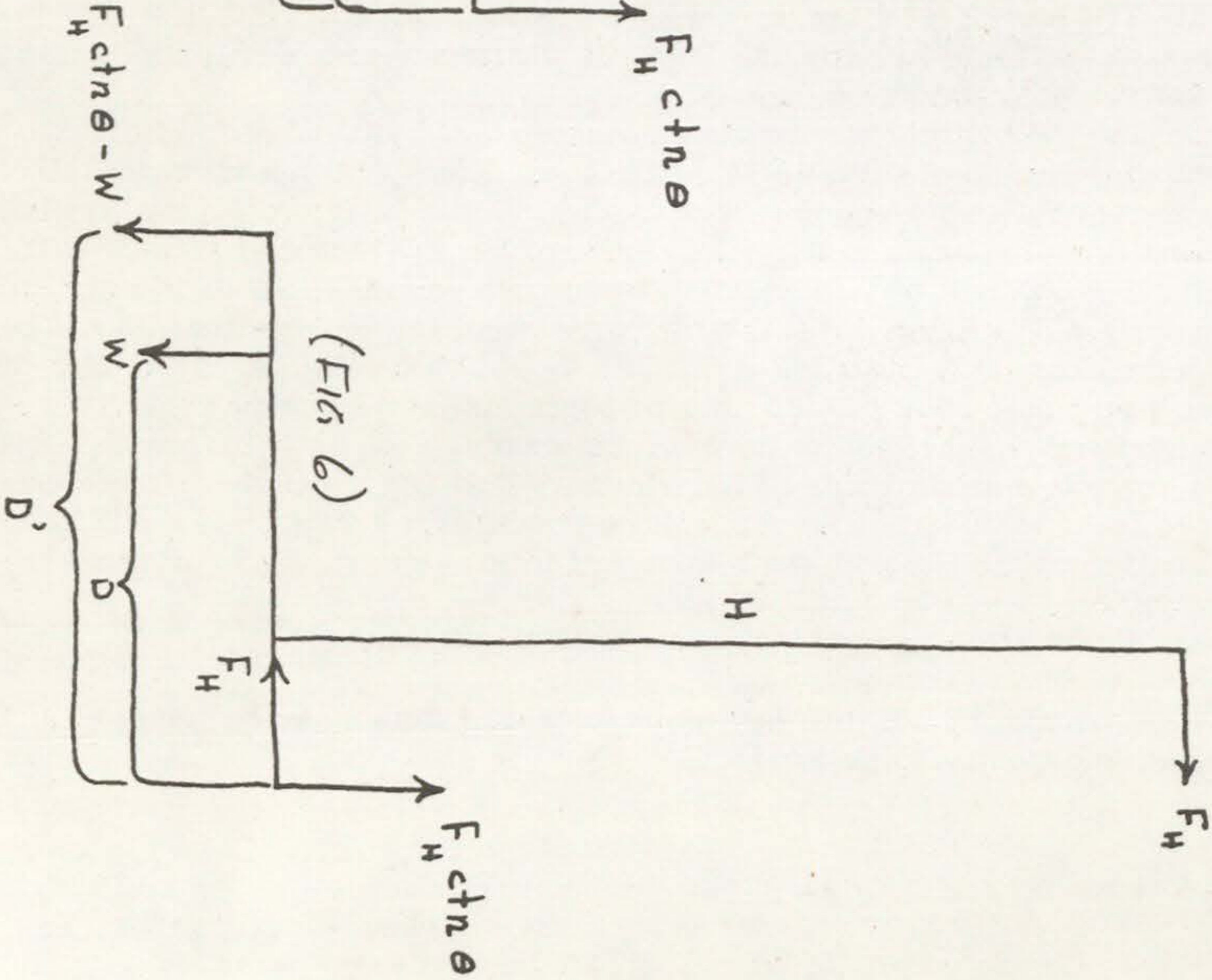
where K_{max} can exceed W. In this way quite large sail forces can be tolerated and high speeds can be expected to be attained.



(FIG 4)



(FIG 5)



(FIG 6)

HYDROFOIL STABILIZERS AND LIFTERS FOR A TRIMARAN.

Letter to Michael Ellison from: Tony Bigras; 10345 Patrica Pl.; Sidney, B.C. Canada.

Dear Michael,

The basic factor limiting speed to date has been stability - both longitudinal and transverse. If stability were unlimited, the thrust available would be unlimited also. This thrust would allow high speeds indeed. Stability can be achieved through the use of dynamic displacement. This is produced by a downward-acting hydrofoil to windward. This displacement is countered by a lifting hydrofoil to leeward. Pitch control is handled by the same downward-acting hydrofoil and a lifting hydrofoil at the bow. We have arrived at the canard configuration.

Ideally, in a gust this craft should bear off rather than luff up - i.e. lee helm. In a boat with a stern rudder, the force countering this for normal sailing would act to increase leeway. Thus, in the canard configuration, weather helm is both unwanted and inefficient.

In order to achieve high lift to drag ratios, inverted T foils are used. The angle of incidence is controlled by mechanical surface sensors which pivot the supporting strut. Both of the rear foils have negative incidence capability. Also, the supporting strut of each side foil is set 2.5 degrees out from the centreline. In this manner, the weather foil provides the lateral resistance. Thus, there is little chance of ventilation down the leeward strut to the low pressure lifting surface. Ventilation could occur on the weather strut but would be of less import as this foil is lightly loaded or negatively loated - in which case ventilation would not reach the low pressure side. With low side loads, ventilation should not be substantial on the bow foil. All foil struts should be fitted with fences in any event.

The craft should be una-rigged to minimize apparent wind shift effects. A wing sail with 20% solid area and an aspect ratio of 4 or 5 set on a radial traveler would be efficient and easily handled. A trimaran configuration with very short outriggers and wide beam would be used. The crew would sit in an aeroplane type cockpit in the stern of the main hull. All foils could be easily retracted forward to reduce draft.

At low speed, the craft would sail buoyancy-stabilized and later foil-stabilized. At liftout, the foils would have an angle of incidence of about 8 degrees which would decrease as the foils rise higher in the water. The stability at this point would be the weight of the craft multiplied by half the beam between struts. As the heeling force increases and the weather foil rises, the foil incidence would become negative. Here, the additional stability would equal the dynamic displacement multiplied by the total beam between the struts.

While the maximum boat speed/wind speed ratio for a water-borne craft probably will not exceed 2.5, a boat of this configuration should attain high speeds in strong winds and may even be powerful enough to use super-cavitating hydrofoils.

Sincerely, Tony Bigras

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THE PRISMATIC COEFFICIENT, RESISTANCE AND SPEED APPLICATION TO MULTIHULLS,

by Harry B. Stover; Rt. 2; Box 434A; Lancaster, VA 22503.

My discussion of the prismatic coefficient in AYRS-FCCG 3 was based on data from Skene's Elements of Yacht Design which in turn borrowed data from Admiral Taylor's Speed and Power of Ships. Since I was working with second-hand data, I decided to borrow a copy of the latter work and have prepared the following study from that.

My only concerns here were skin friction and wave-making resistances. Since I was interested in comparative resistances at several prismatic coefficients (C_p) and at several displacement - length ratios (DLR), I felt it would be acceptable to omit consideration of eddy-making and wind resistances, sideslip drag and others. I do not believe that these are affected appreciably by choice of prismatic coefficient.

Prismatic Coefficient is defined as: $C_p = V/A_m$ LWL, or the displacement in cubic feet (64 lbs. per cubic feet) divided by the product of the underwater area of the maximum body section times the length on the waterline in square feet and feet respectively. DLR is defined as: DLR = _ $/(.01LWL)^3$, or the displacement in tons (2240 lbs each) divided by one one-hundredth of the length on the waterline cubed.

My studies are based on a series of hulls all of 25 ft. waterline length, without appendages. The thrust of my remarks concerns multihulls, because I think only multihulls have the sail carrying ability required to attain the speeds necessary to justify

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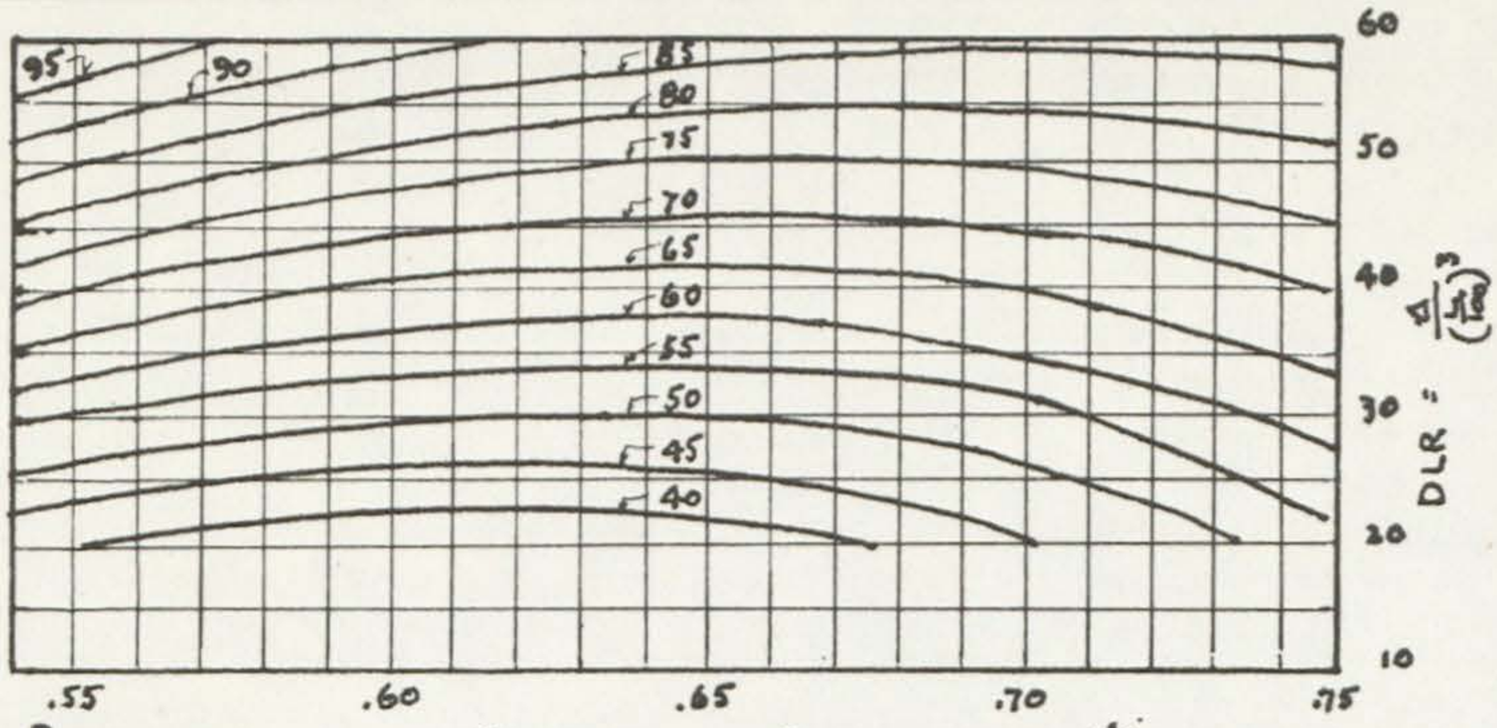


$\frac{B}{H} = 2.25$ PRISMATIC C_p $V/\sqrt{L} = 2.00$

RESIDUARY RESISTANCE - POUNDS PER TON Δ

FIG. 1

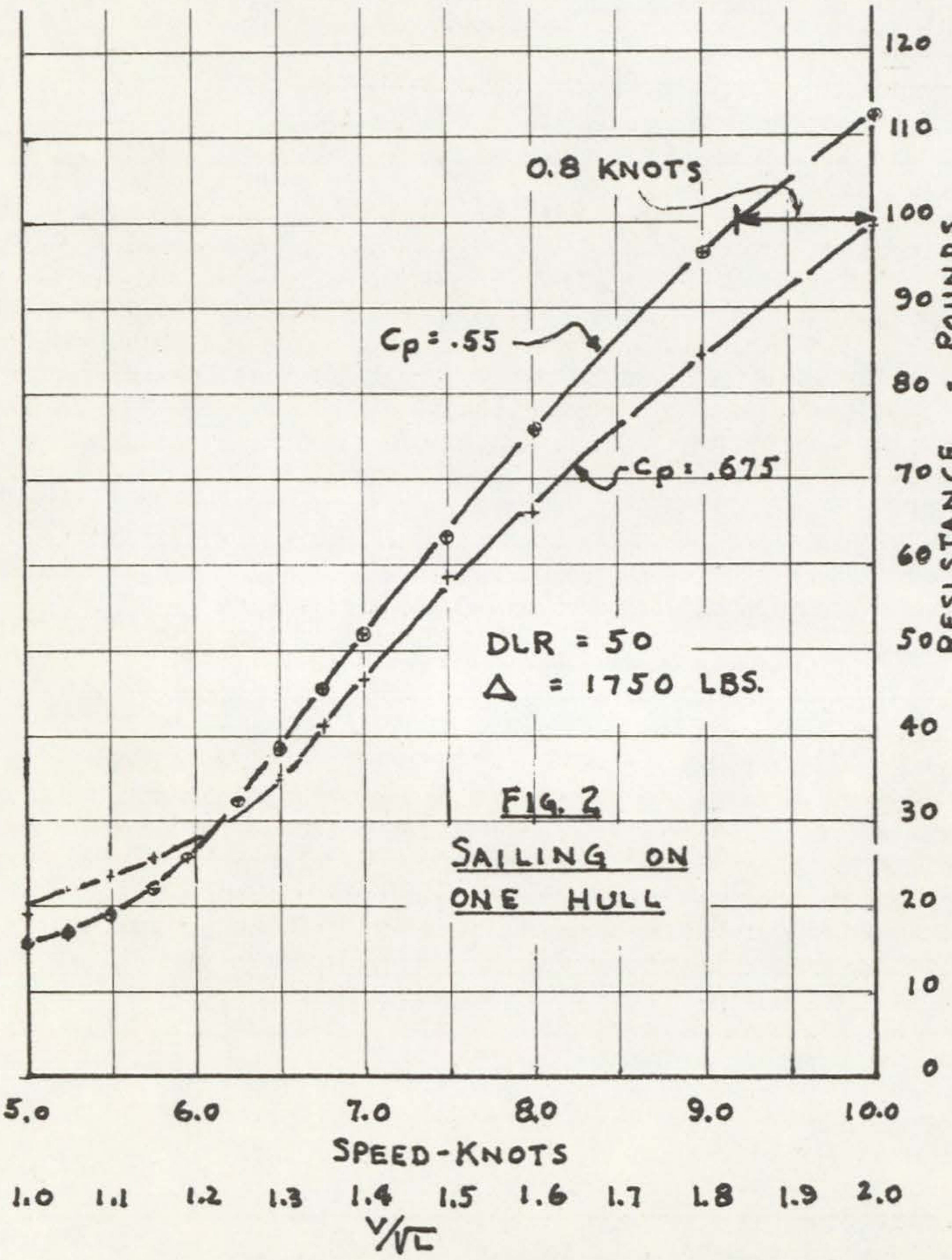
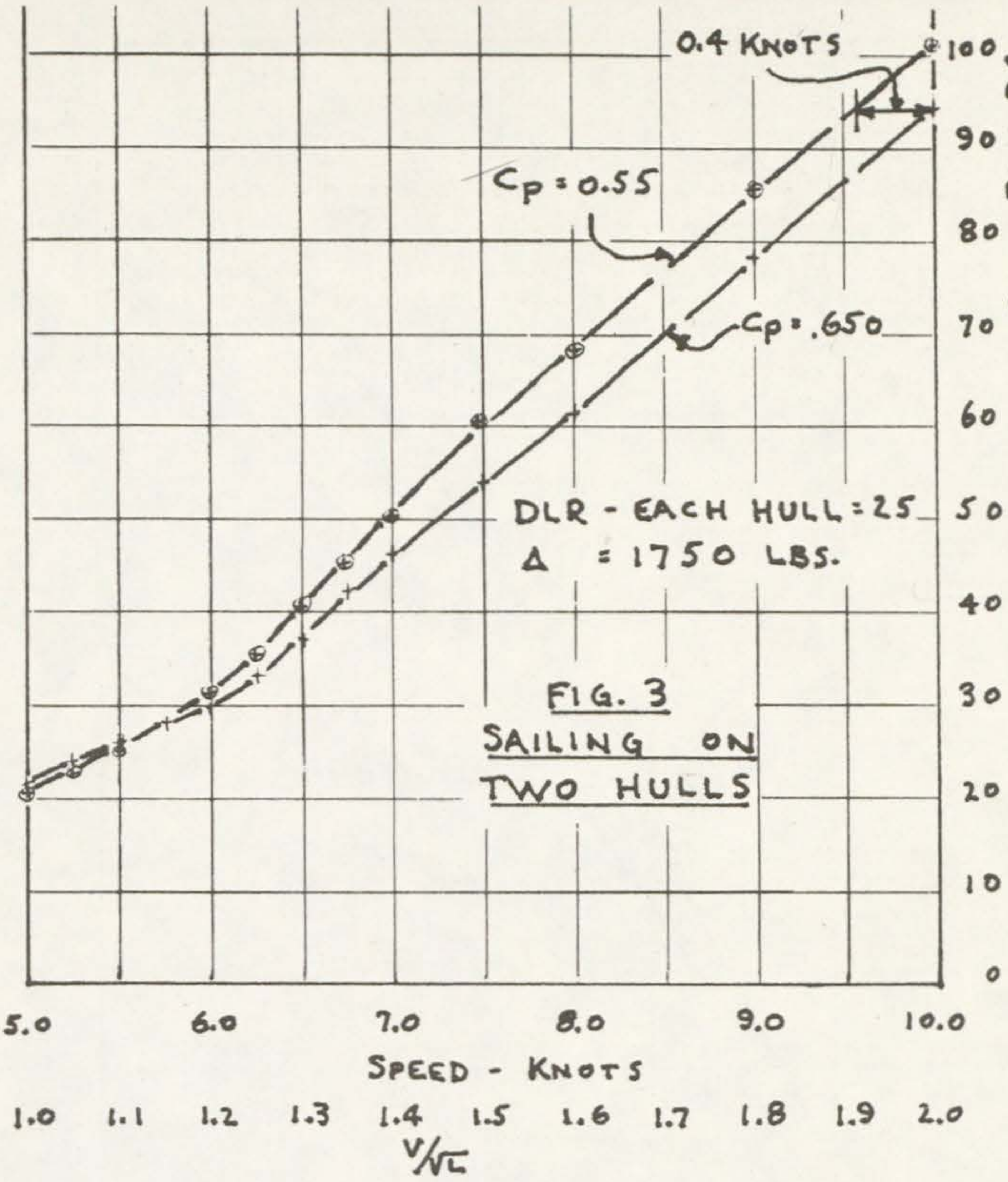


FIG. 2

SAILING ON ONE HULL



such prismatics. Hulls are assumed to have semi-circular midship sections. Once the prismatic and the DLR are selected, the hull shape is defined including midship section area, beam, and maximum girth.

Approximation of wetted area was made by using John Morwood's formula: S = 3/4 x LWL x Perimeter Maximum Girth Underwater. Knowing wetted surface, it is a simple matter to determine frictional resistance: $R_f = C_f \times S \times V^{1.83}$ for $C_f = 0.0125$, the coefficient of friction for an LWL of 25 feet; V = speed in knots; and S = wetted surface area in square feet. (See AYRS AIRS 10, Page 14).

To determine wave making or residuary resistance - R_r, I used the method explained in Speed and Power of Ships. It is based on residuary resistance in pounds per ton of displacement and is the same for any size hull of the same shape at the same $V/\sqrt{L}$. Figure 1 is traced from this reference for a $V/\sqrt{L} = 2.0$. Note that this chart is for a beam to draft ratio (B/H) of 2.25 and not 2.0 as required for semi-circular midships sections. Taylor provides curves only for this ratio and 3.75, and it is customary to interpolate or extrapolate to obtain the resistance for the desired beam/draft ratio. I assumed that 2.25 was close enough to 2.0, and all my work is based on this assumption leading to a slight over-estimation of resistance.

A set of resistances was worked up, based on the above, for 25 ft. waterline hulls with prismatics varying from 0.50 to 0.70 and with DLR varying from 25 to 60. These DLR's correspond to displacements from 875 pounds to 2100 pounds for the 25 ft. hulls. This was done for a speed of 10 knots for all combinations, and resistance curves were prepared for each DLR at what I considered to be the optimum prismatic in each case. For comparative purposes, another set of resistance curves was prepared for each DLR using a prismatic of 0.55 which I believe is about what is ordinarily used. Results are shown in the tables and on the plots.

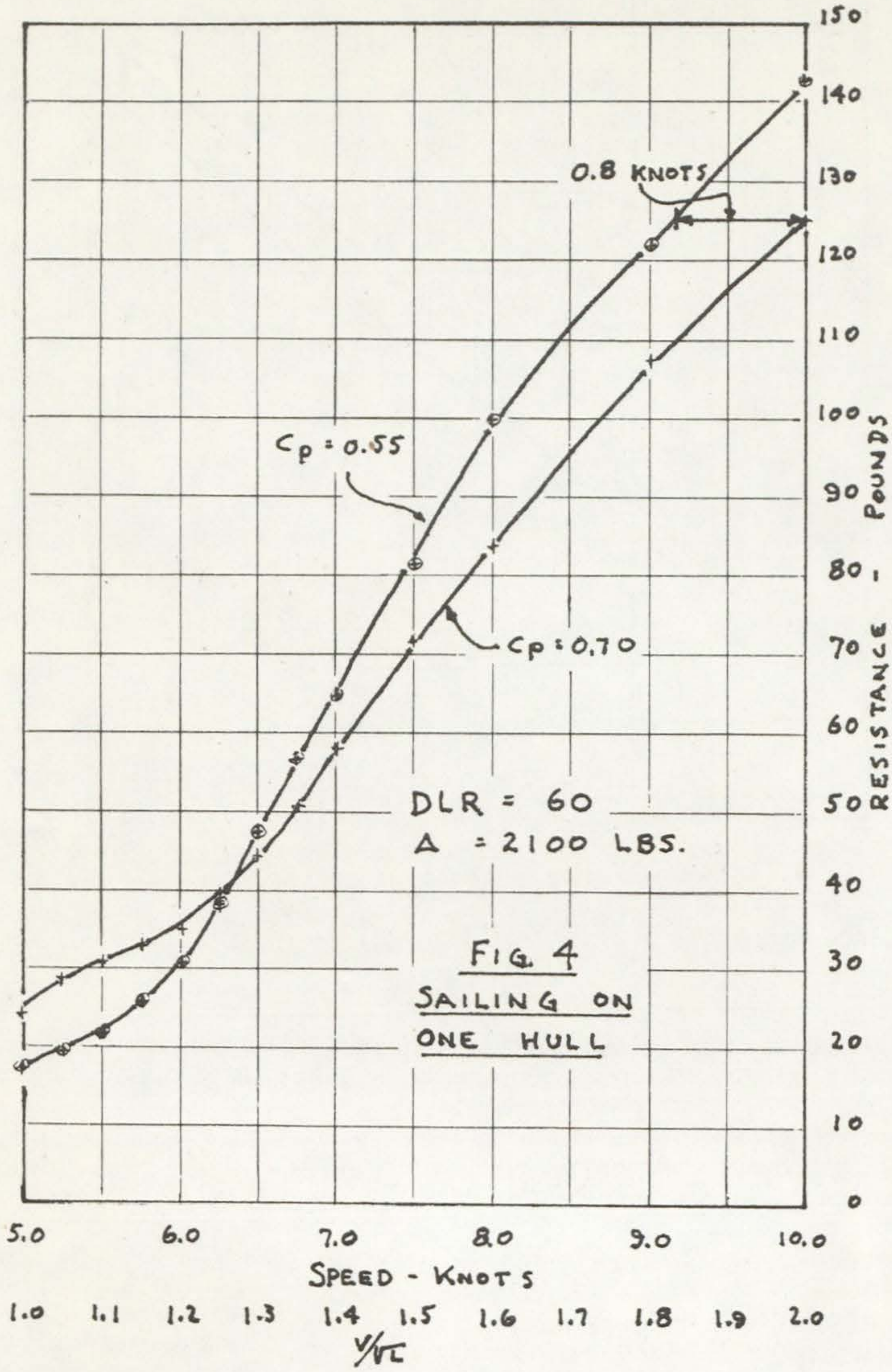
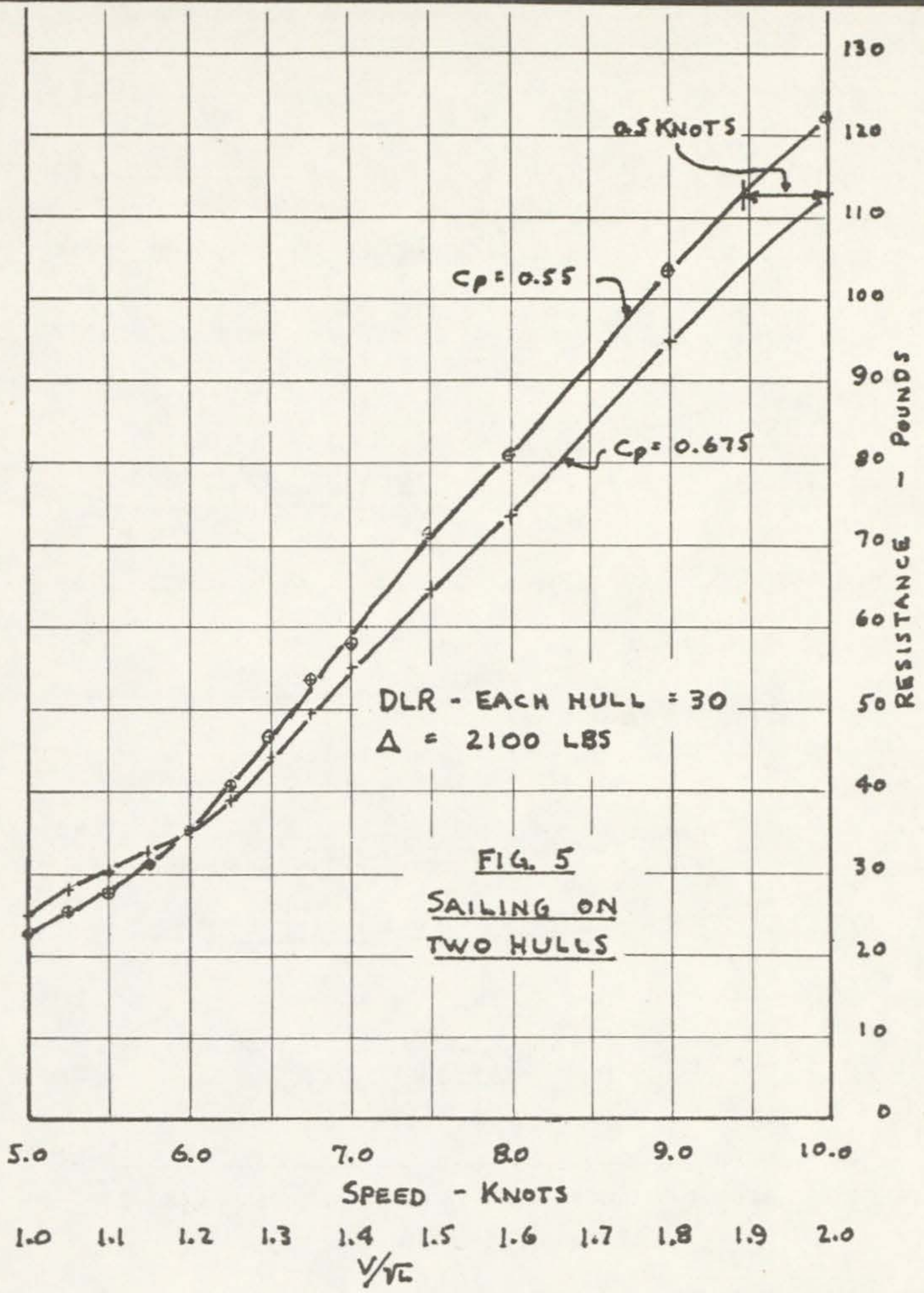


FIG 4
SAILING ON ONE HULL

One result is that beam and wetted surface of hulls with high prismatics are considerably less than those for hulls with low prismatics. This has a kind of cumulative effect on resistance at high speeds. Both residuary and frictional resistances are lowered. A further effect is that overall weight is reduced. I made no allowance for the reduced weight but did for the reduction in frictional resistance.

As a matter of interest, I have shown the displacement to resistance ratio. This number is equivalent to lift-drag ratio and shows that for speeds of at least 10 knots, for 25 ft. hull, it is more efficient to support weight by buoyancy than by planing or hydrofoils.

Some interesting comparisons can be made from these data. For example, one can imagine that a catamaran is designed to sail at top speed in either of two conditions: 1) one hull flying, 2) both hulls somehow displacing an equal amount of water. A catamaran of 1750 lbs. displacement sailing in condition (1) has a resistance of about



100 lbs. at a speed of 10 knots, as can be seen in Figure 2. The same weight catamaran designed for condition (2) - sailing flat - has a resistance of about 90 lbs. from Figure 3. This is determined by taking the total resistance of two 875 lb. hulls. This same sort of comparison is shown in Figures 4 and 5 for a 2100 lb. catamaran. It appears that a multihull designed to sail on two hulls is basically faster than one designed to sail on one hull at high speed, provided there is no interference between hulls. Another conclusion is that a proa can be made faster if the stabilizing hull is placed to leeward and is of the same length and displacement as the main hull, if overall weight is kept the same.

Figure 6 is a plot of resistance in pounds vs. prismatic coefficient for $V/\sqrt{L} = 2.0$ or 10 knots, for the 25 ft. hulls, for several displacements. Optimum prismatic varies between 0.62 and 0.70 or even higher depending upon DLR.

Figure 7 is a cross-plot of Figure 6 which shows that at higher DLR's, the selection of the proper prismatic is even more important, provided we can carry enough sail area to drive the hull at $V/\sqrt{L} = 2.0$.

Figures 8 and 9 show the penalty for assuming conventional prismatic coefficients and one hull flying vs. optimum prismatic and both hulls equally immersed. In the case of a 1750 lb. boat, the increase in speed for the same driving force is 1.1 knots. For

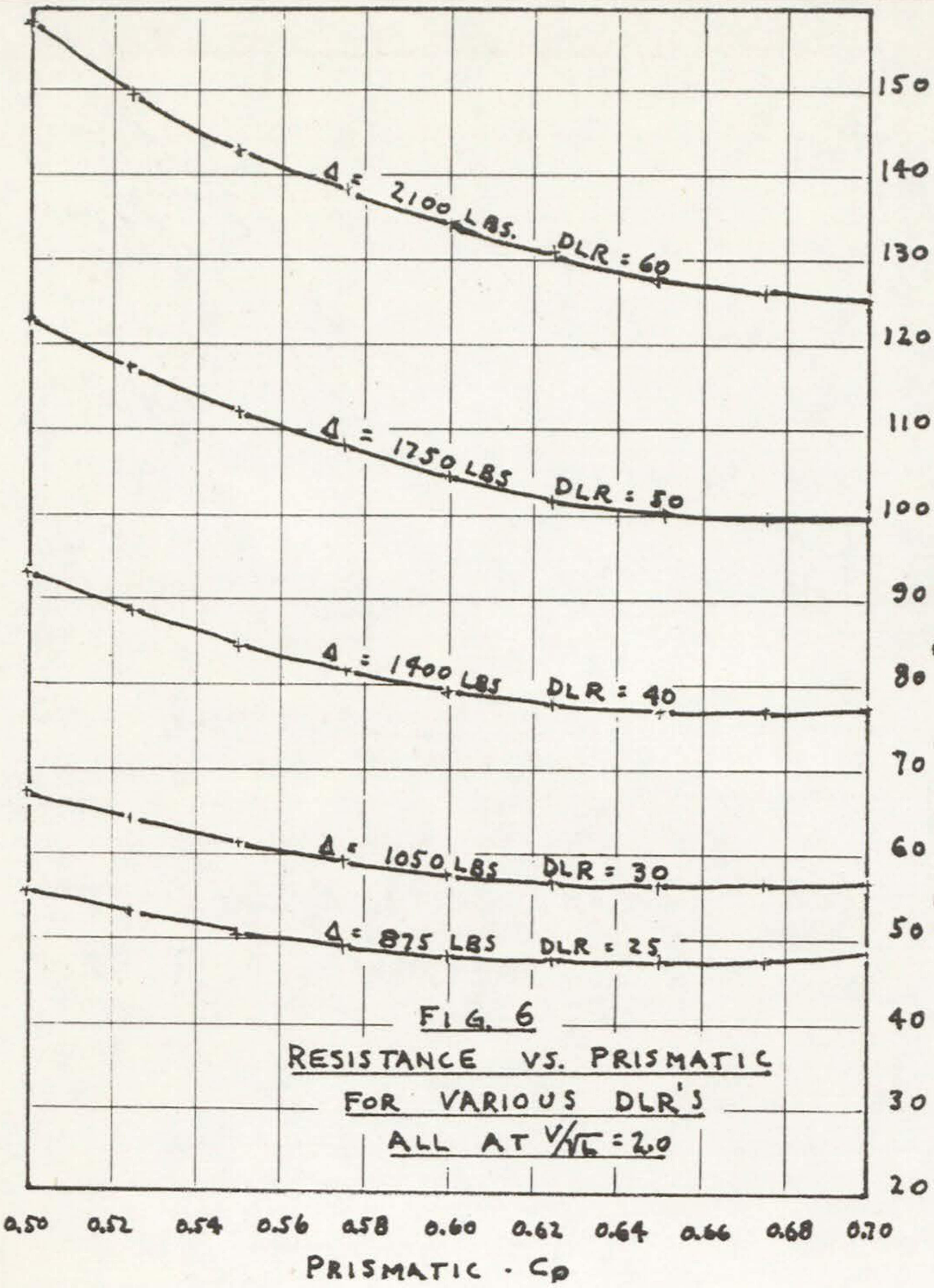


FIG. 6

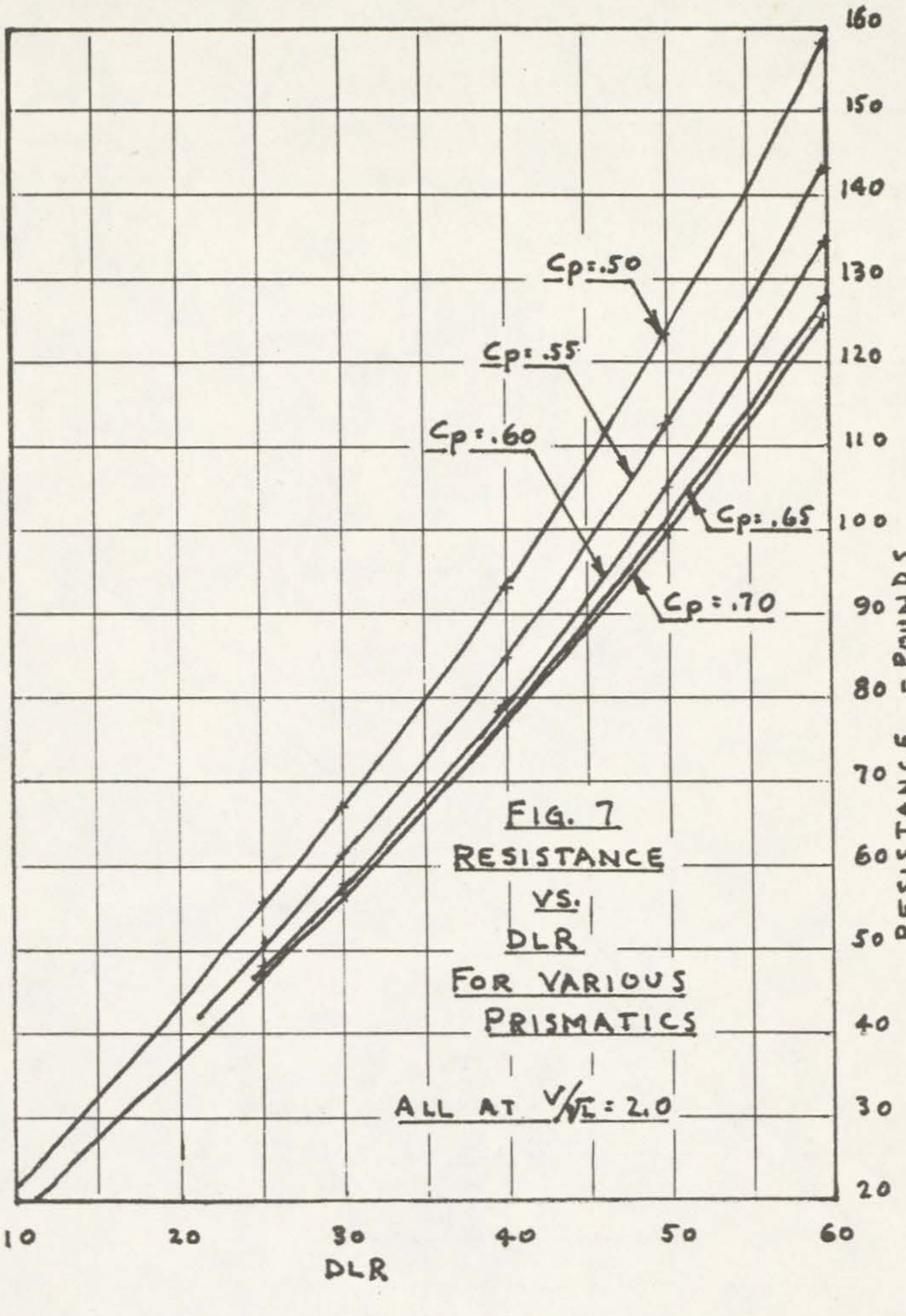
RESISTANCE VS. PRISMATIC FOR VARIOUS DLR'S ALL AT $V/\sqrt{L} = 2.0$

a 2100 lb. boat, the increase is 1.4 knots.

John Morwood states that multihulls can attain speeds of 4 or 5 times $V/\sqrt{L}$. All my work stops at 2.0 because I have no data beyond that point. From Figures 8 and 9 it appears to me that the trend for higher speeds continues to diverge.

My current thinking is that a fast sailing multihull should have a prismatic coefficient between 0.65 and 0.70. Since this will result in increased drag at lower speeds, I would have plenty of sail area for slow speeds and means to reduce that area in high winds.

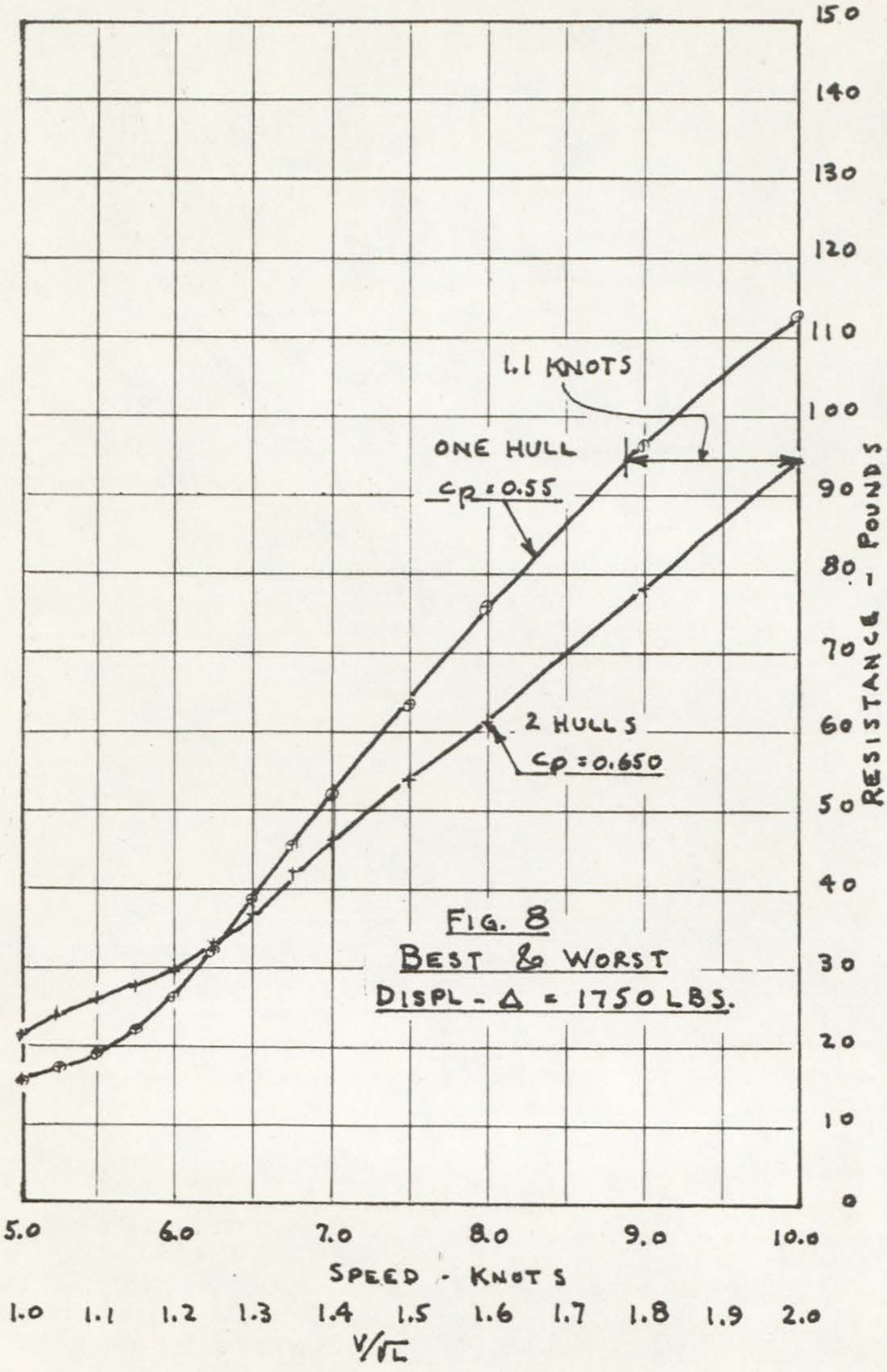
Editor's Note: Taylor's data was corrected slightly and extended to include B/H = 3.00 in: A Reanalysis of the Original Test Data for the Taylor Standard Series. Taylor Model Basin Report 806, March, 1954. Yacht designers often dismiss ship model tests as being inappropriate, but I believe this is not correct, as models for ship tests are within a factor or two or three of a full-scale yacht - 20 feet or so long in the case of Admiral Taylor's. For a reference series such as this, hull forms similar to those of a particular yacht may be selected, as Harry Stover did in choosing B/H = 2.25, and keel, rudder and other appendages may have their appropriate resistance factors added in. One could question the accuracy of the Taylor data at its upper limit of $V/\sqrt{L} = 2.0$, and it is unfortunate that higher values were not used. The excellent Series 64 tests went up to $V/\sqrt{L} - 5.0$ but unfortunately held prismatic coefficient constant at 0.63. It is interesting, that the Series 64 tests showed that resistance does not always decrease



uniformly with DLR, but that there are minima, and hence optimum DLR's for constant prismatics.

Harry and I do not agree on the value of higher prismatics for single hull craft, and that his work is only applicable to multihulls. I feel it applies to any high speed boat whatever the number of hulls and method of propulsion until planing comes into the picture.

Even today, some disagree about the importance of the prismatic coefficient in the design of high speed sailboats and its relation with DLR. Prof. Castles predicts from theoretical considerations using wave drag theory that high prismatics are necessary for high speed, and he used 0.75 for his very successful catamaran. He believes even higher prismatics should be used. Harry Morss' PROATYPE experiment has a prismatic of 0.61 for his main canoe hull, and Joe Norwood uses 0.60 for the main hull and 0.61 for the float hull for his proa hydrofoil sailboat: THUNDERBOLT (AYRS AIRS 9,46). As Harry Stover so rightly says, more sail area can be carried to overcome the small increase in resistance at lower speeds from using the higher prismatic.



Admiral Taylor had this to say: "It is seen that for nearly every speed there is, for a given DLR, a distinct minimum of resistance corresponding to a definite prismatic coefficient. For low and moderate speeds up to $V/\sqrt{L} = 1.1$, the best prismatic is between 0.50 and 0.55. Above this point, however, the optimum prismatic increases rapidly, reaching about 0.65 when $V/\sqrt{L} = 1.5$ and being a little greater still at 2.0" Taylor cited a particular example to show that the resistance was more than doubled by using the incorrect lower prismatic. (0.55 instead of 0.65.)

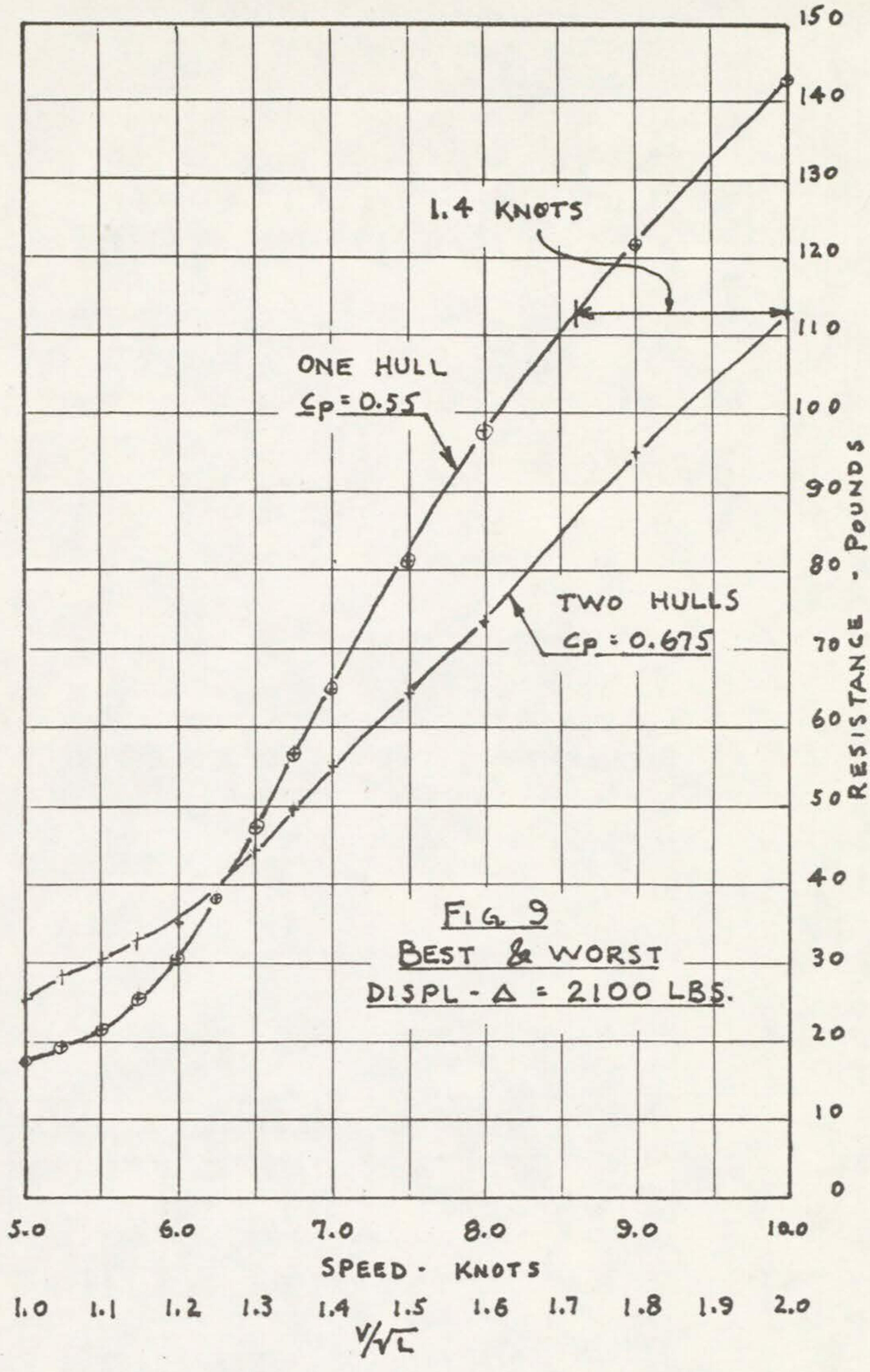


FIG. 9
BEST & WORST
DISPL - Δ = 2100 LBS.

NOTES FOR TABLES I THROUGH V

LINE 2 TONS DISPLACEMENT
$\Delta = DLR \times (L/100)^3 = DLR \times 0.01562$ FOR 25' HULL

LINE 3 POUNDS DISPLACEMENT
Δ = LINE 1 × 2240

LINE 4 READ FROM CURVES IN "SPEED AND POWER"

LINE 5 TOTAL WAVE MAKING RESISTANCE
$= \text{LINE } 2 \times \text{LINE } 4$

LINE 6 BEAM

$$\frac{\pi B^2}{8} \times LWL \times C_p \times \frac{1}{35} = \Delta_{TONS} = \text{LINE } 2$$

$$B = \sqrt{\frac{\Delta \times 89.126}{LWL \times C_p}}$$

LINE 7 GIRTH ⊄ $= (\pi \times B)/2$

LINE 8 WETTED SURFACE = W.S. $= 3/4 \times LWL \times \text{LINE } 7$

LINE 9 $R_f = V^{1.83} \times f \times W.S.$

LINE 10 TOTAL RESISTANCE = LINE 5 + LINE 9 *

LINE 11 L/D = LIFT-DRAG RATIO = LINE 3/LINE 10.

* ITEMS COPIED INTO TABLES TO THREE SIGNIFICANT FIGURES. AS A RESULT LINE 10 DOES NOT ALWAYS EXACTLY EQUAL LINE 5 + LINE 9

1	C_p		0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
2	Δ	TONS	0.391	→	→	→	→	→	→	→	→
3	Δ	LBS.	875.	→	→	→	→	→	→	→	→
4	R_P/TON	LBS.	56.0	52.0	47.0	45.0	44.0	44.0	44.5	46.0	49.0
5	TOTAL WAVEMAKING	LBS.	21.9	20.3	18.4	17.6	17.2	17.2	17.4	18.0	19.1
6	BEAM	FT.	1.67	1.63	1.59	1.56	1.53	1.49	1.46	1.44	1.41
7	GIRTH ⊄	FT.	2.62	2.56	2.50	2.45	2.40	2.34	2.29	2.26	2.21
8	WETTED SURFACE	SQ.FT.	49.1	48.0	46.9	45.9	45.0	43.9	42.9	42.4	41.4
9	R_f	LBS.	34.0	33.3	32.5	31.8	31.2	30.4	29.7	29.4	29.0
10	TOTAL RESISTANCE	LBS.	55.9	53.6	50.9	49.4	48.4	47.6	47.1	47.3	48.2
11	Δ/R = L/D		15.7	16.3	17.2	17.7	18.1	18.4	18.6	18.5	18.2

TABLE I

RESISTANCE AT VARIOUS PRISMATICS

$V/\sqrt{L} = 2.0$ $V = 10.0$ KNOTS DLR $= \Delta / \left(\frac{L}{100}\right)^3 = 25$

			0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
1	C_p		0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
2	Δ	TONS	0.469	→	→	→	→	→	→	→	→
3	Δ	LBS.	1050	→	→	→	→	→	→	→	→
4	R_r/TON	LBS.	64.0	59.0	55.0	52.0	50.5	50.0	50.5	52.0	54.0
5	TOTAL WAVE MAKING	LBS.	30.0	27.7	25.8	24.4	23.7	23.4	23.7	24.4	25.3
6	BEAM	FT.	1.83	1.78	1.74	1.71	1.67	1.64	1.61	1.57	1.55
7	GIRTH ⊕	FT.	2.87	2.80	2.73	2.69	2.62	2.58	2.53	2.47	2.43
8	WETTED SURFACE	SQ.FT.	53.8	52.5	51.2	50.4	49.1	48.4	47.4	46.3	45.6
9	R_f	LBS.	37.3	36.4	35.5	35.0	34.0	33.5	32.9	32.1	31.6
10	TOTAL RESISTANCE	LBS.	67.3	64.0	61.2	59.3	57.7	57.0	56.5	56.5	56.9
11	$\Delta/R = L/D$		15.6	16.4	17.1	17.7	18.2	18.4	18.6	18.6	18.5

TABLE II

RESISTANCE AT VARIOUS PRISMATICS

$V/\sqrt{L} = 2.0$ V = 10.0 KNOTS DLR = $\Delta/(L/100)^3 = 30$

			0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
1	C_p		0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
2	Δ	TONS	0.625	→	→	→	→	→	→	→	→
3	Δ	LBS.	1400	→	→	→	→	→	→	→	→
4	R_r/TON	LBS.	80.0	74.5	70.0	66.5	64.0	63.0	63.0	64.0	65.0
5	TOTAL WAVEMAKING	LBS.	50.0	46.6	43.7	41.6	40.0	39.4	39.4	40.0	40.6
6	BEAM	FT.	2.11	2.06	2.01	1.97	1.93	1.89	1.85	1.82	1.78
7	GIRTH ⊕	FT.	3.31	3.24	3.16	3.09	3.03	2.97	2.91	2.86	2.80
8	WETTED SURFACE	SQ.FT.	62.1	60.8	59.3	57.9	56.8	55.7	54.6	53.6	52.5
9	R_f	LBS.	43.0	42.1	41.1	40.1	39.4	38.6	37.8	37.1	36.4
10	TOTAL RESISTANCE	LBS.	93.0	88.6	84.8	81.7	79.4	77.9	77.2	77.1	77.0
11	$\Delta/R = L/D$		15.1	15.8	16.5	17.1	17.6	18.0	18.1	18.2	18.2

TABLE III

RESISTANCE AT VARIOUS PRISMATICS

$V/\sqrt{L} = 2.0$ V = 10.0 KNOTS DLR = $\Delta/(L/100)^3 = 40$

			0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
1	C_p		0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
2	Δ	TONS	0.781	→	→	→	→	→	→	→	→
3	Δ	LBS.	1750	→	→	→	→	→	→	→	→
4	R_r/TON	LBS.	96.0	90.0	85.0	81.0	78.0	75.5	74.5	74.5	75.5
5	TOTAL WAVEMAKING	LBS.	75.0	70.3	66.4	63.3	60.9	59.0	58.2	58.2	59.0
6	BEAM	FT.	2.36	2.30	2.25	2.20	2.16	2.10	2.07	2.03	2.00
7	GIRTH ⊕	FT.	3.71	3.61	3.53	3.46	3.39	3.30	3.25	3.19	3.14
8	WETTED SURFACE	SQ.FT.	69.6	67.7	66.2	64.9	63.6	61.9	60.9	59.8	58.9
9	R_f	LBS.	48.2	46.9	45.9	45.0	44.0	42.9	42.2	41.4	40.8
10	TOTAL RESISTANCE	LBS.	123.2	117.2	112.3	108.3	104.9	101.9	100.4	99.6	99.8
11	$\Delta/R = L/D$		14.2	14.9	15.6	16.2	16.7	17.2	17.4	17.6	17.5

TABLE IV

RESISTANCE AT VARIOUS PRISMATICS

$V/\sqrt{L} = 2.0$ V = 10.0 KNOTS DLR = $\Delta/(L/100)^3 = 50$

			0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
1	Cp		0.500	0.525	0.550	0.575	0.600	0.625	0.650	0.675	0.700
2	Δ	TONS	0.937	→	→	→	→	→	→	→	→
3	Δ	LBS.	2100	→	→	→	→	→	→	→	→
4	Rr/TON	LBS.	113.	105.	99.	95.	92.	89.	87.	86.5	86.
5	TOTAL WAVEMAKING -	LBS.	105.9	98.4	92.8	89.0	86.2	83.4	81.5	81.1	80.6
6	BEAM	FT.	2.58	2.52	2.46	2.42	2.36	2.32	2.27	2.22	2.18
7	GIRTH ⊕	FT.	4.05	3.96	3.86	3.80	3.71	3.64	3.57	3.49	3.42
8	WETTED SURFACE	SQ. FT.	75.9	74.3	72.4	71.3	69.6	68.3	66.9	65.3	64.1
9	R_f	LBS.	52.6	51.5	50.2	49.4	48.2	47.3	46.4	45.2	44.4
10	TOTAL RESISTANCE	LBS.	158.5	149.9	143.0	138.4	134.4	130.7	127.9	126.3	125.0
11	$\Delta/R = L/D$		13.2	14.0	14.7	15.2	15.6	16.1	16.4	16.6	16.8

TABLE V

RESISTANCE AT VARIOUS PRISMATICS

$V/\sqrt{L} = 2.0$ $V = 10.0$ KNOTS $DLR = \Delta/(\frac{L}{100})^3 = 60$

Δ	875 LBS		1050 LBS		1750 LBS		2100 LBS	
Cp	0.550	0.650	0.550	0.675	0.550	0.675	0.550	0.700
V ↓								
5.00	10.3	10.7	11.3	12.5	15.3	19.2	17.1	24.2
5.25	11.4	12.0	12.7	14.1	17.3	22.2	19.6	28.7
5.50	12.5	13.0	13.9	15.1	19.2	23.7	21.8	30.7
5.75	14.0	14.0	15.6	16.4	22.3	25.6	25.6	33.0
6.00	15.6	14.9	17.6	17.5	26.3	27.7	30.7	35.4
6.25	17.8	16.7	20.4	19.5	32.2	31.5	38.6	39.7
6.50	20.2	18.6	23.4	22.0	38.9	35.4	47.4	44.6
6.75	22.6	21.2	26.6	24.8	45.6	41.1	56.6	50.9
7.00	25.0	23.1	29.0	27.5	52.0	46.7	65.0	58.3
7.50	30.2	27.0	35.8	32.3	63.9	58.9	81.4	71.7
8.00	34.1	30.7	40.4	36.8	75.8	66.2	98.0	83.9
9.00	42.7	39.1	51.7	47.5	96.3	84.9	121.9	107.3
10.00	50.8	47.1	61.2	56.5	112.3	99.6	142.9	125.0

TABLE VI

DATA FOR RESISTANCE CURVES

NOTE - NOT DONE FOR 1400 LB. HULL
EXCEPT AT 10 KNOTS

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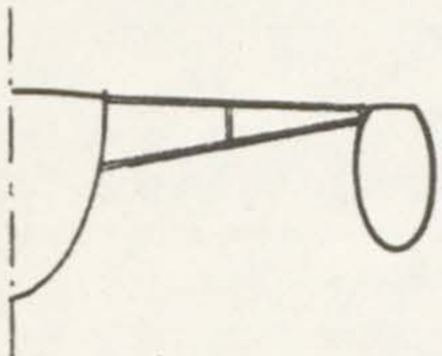
<u>MULTIHULL CROSS BEAMS</u>, by Wallace Venable; Rt. 1, Box 229A; Morgantown, WV 26505.

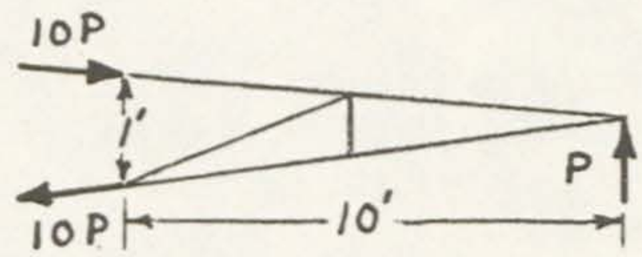
The literature on yacht design and naval architecture contains suprisingly little information on the design of structures through the use of stress analysis. To the extent that designers are willing to utilize established scantlings, this causes few problems, but when radically new configurations are tried, structural failure is all too common. The observations described here may help some of the members to apply a bit more analysis to the design of cross beams in float and foil stabilized craft.

In actuality, many of the cross beams used in racing multihulls are not truely beams. Consider the system used on such boats as TRUMPETER, FT, and the TANGO. (See sketch 1A.) Stabilizing forces generated by the floats on these craft are transmitted to the main hull by relatively simple trusses. Properly designed, trusses are able to carry very large loads for their weight, but are prone to sudden failure. In sketch 1B, the load and dimension relationships on a simple triangular truss are shown. It is observed that the upper member carries a compressive load which may be as much as ten or twenty times the bouyancy of the float. This member behaves as a column, and fails by buckling, as does a spinnaker pole, with alarming speed.

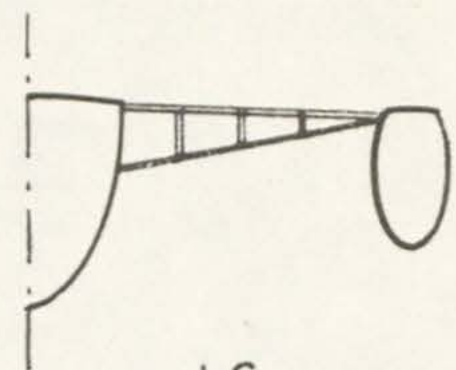
A basic principle of column behavior is that if the cross-section of the member is held constant, the strength of the member varies as the inverse square of the effective length of the column. Thus, the strength of the cross member shown in sketch 1C may be twice as strong as the one in 1A, even if both are constructed of the same extrusion or molding.



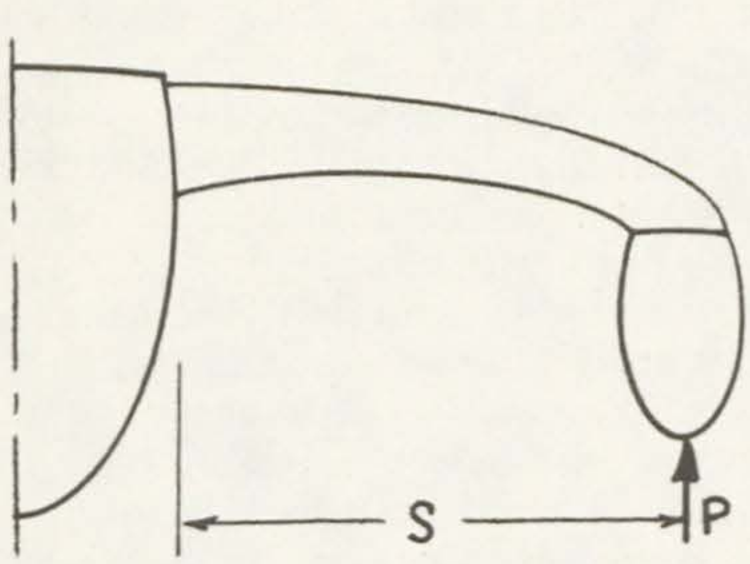
1A



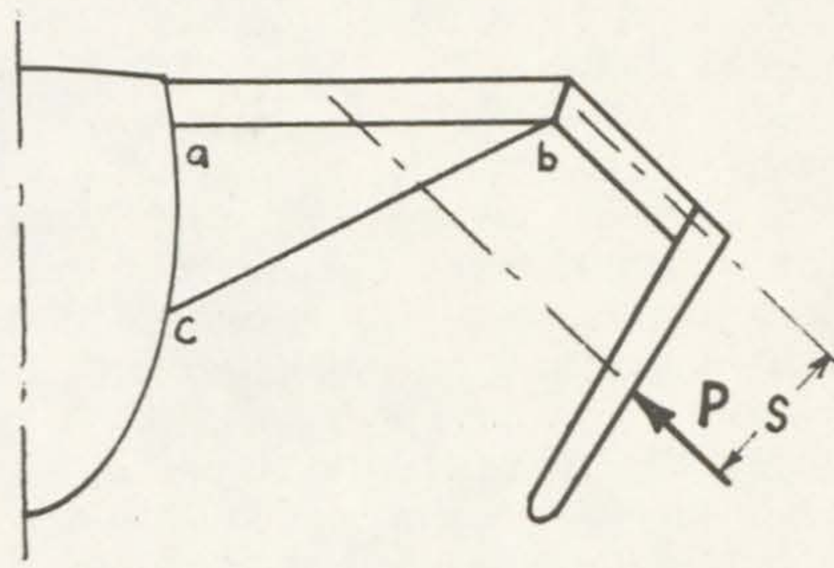
1B



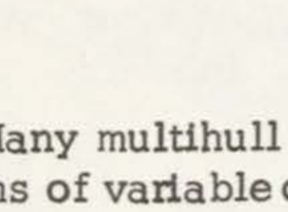
1C



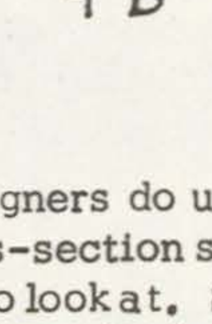
2



3



4A



4B

4C

4D

Many multihull designers do use true beams for outrigger connections. The arched beams of variable cross-section seen on GULFSTREAMER and in sketch 2 are often both effective and pleasant to look at. Since the internal bending moment is directly proportional to the distance from the load (in this case the float), the tip of the beam may be considerably smaller than the root where the beam connects to the hull. The curvature of the beam may complicate the construction a great deal, but it has little effect on the strength when used to support bouyant loads.

The curved beam of variable cross-section should not be applied to foil stabilized craft without a bit more consideration. Sketch 3 shows the beam configuration used on MANTIS IV. In a foiler, the force on the outrigger is no longer primarily a vertical one. Maximum bending moments in the beam will occur at points with the greatest distance from the line of action of the resultant force. In the figure shown, these maxima would be expected at a and b. On MANTIS, a stay was fitted between b and c, thus there is a single important maximum at b. In fact, this point is on concern for four different reasons; first, the maximum moment occurs there; second, it is a joint between two straight segments; third, there may be stress concentrations due to the abrupt change in the beam's direction; and finally, it is the attachment point for a stay.

Thus far only vertical and transverse loads on outriggers have been considered. When pitching forces come into play another problem arises. A foil or float entering a wave will be lifted more strongly at one end than the other. If the float is held by two beams, this will result in an increased load on one as shown in sketch 4A. This causes no particular problem if the beams are designed to carry the increased load. On the other hand, if the float is held by a single member, it must carry both a bending load and a torque as shown in 4B. This torque or twisting force introduces a further complication.

A full discussion of the stresses in members carrying twisting loads is too complicated for this note, but it is important to understand that the stress at any point in cross-section will be proportional to its distance from the centroid (center) of the section if we require it to behave elastically. Cross-sections which are approximately round or square are relatively efficient in handling torques since a large portion of the area carries about the same stress. Wings and faired beams, however, may have widely differing stresses in different places. A wing constructed as shown in 4C will concentrate most of the force resulting from torque in the spars which make up its two edges. This is also the location of the maximum stress, thus this structure acts as if it were two beams similar to 4A. A wing with a single spar acts in a different manner. The spar in sketch 4D must carry most of the force as the skin is too thin to contribute substantial strength. At the same time, the maximum stress will occur at the leading and trailing edges. Unless the spar is extremely stiff, the wing may twist enough to cause the edges to fracture without endangering the strangth of the wing as a whole.

It is, of course, easy enough to design simple cross beams with more then necessary strength. The problems result from the need to keep water and wind resistance and weight to a minimum. Most yacht designers have little or no training in the mechanics of materials, and few structural designers have the combination of experience and information needed to be of assistance in a multihull project.

The members of AYRS have done a great deal to further understanding of the hydrodynamic aspects of yacht design. If this greater knowledge is to be employed safely, increased understanding of yacht structures will surely be necessary. Perhaps the Society should organize activities which will bring together the knowledge of engineers and naval architects for the benefit of all yachtsmen.

Editor's Note: Prof. Venable has proposed that the AYRS establish a working committee on yacht strength, initially to be charged with a study of multihull cross beams. Such a group should include: professional engineers, designers and builders. Studies would be based on actual experiences at sea, and information on failures and successful designs would be solicited from designers, sailors and builders.

This seems like a good idea to me, and I ask the AYRS Membership for volunteers to become part of this working committee. I also ask for someone to offer to chair and organize this group. I have over-committed myself to AYRS affairs and will need someone to take on this task, or we will drop it. Ross Carter and Jack Warner have offered to participate, and I seek others abroad and in the U.S. to do likewise.

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THE SOLID FREE-STANDING MAST,

by Edmund B. Mahinske; 5515 Ivor Street; Springfield, VA 22151.

Until recently, I took for granted - as I'm sure many of you did - that a sailing vessel had to have its masts supported by a maze of shrouds, spreaders, and stays, turnbuckles, tangs ... and all of the other attendent paraphernalia. After all, many good minds over the span of endless years paid much attention to this aspect. And in boat design we are forever and severely admonished to be guided by what has gone before, the "voice of experience". Accordingly, I little wondered about the necessity of guying masts or possible alternatives thereto; I assumed such guying a natural and necessary part of the package.

And then a "heretic" comes along and says, "'Taint so!". The claim is made that free-standing masts, devoid of the wiring maze and the rest goes with it, is both feasible and practical. After a number of strenuous objections on my part, I grudgingly turned to paper and pencil to determine the feasibility of free-standing masts. This takes a bit of doing which, I confess, is the reason for much of my original recalcitrance. Well, as I will show presently, such masts are feasible and worthy of consideration. Note that I stress the word feasible because I carried my analysis to the point of showing such and no more. What I asked myself was whether such masts were worth the worry. They are.

In what transpires below, I will spare the reader the torture of diagrams and calculations and just report the results. If there are some who are interested in these omissions, perhaps they can be made the subject of a future article.

In order to analyze a free-standing mast, the first thing that needs to be done is to postulate the conditions which are to stress the mast to its limits without failure. A determination of that stress would then be used in calculations to derive the dimensions of the mast cross sections. If the cross section turns out to exceed the beam of a resonable boat, quite obviously a free-standing mast would not be feasible or hardly practical. I think the reader will be surprised by the actual outcome.

To preclude any area of contention about how a resultant wind force presents itself upon the mast with respect to its relative orientation to the mast cross section, I chose a circular cross section. As a result, the direction of the resultant wind force, as far as its stressing of the mast is concerned, is immaterial: the mast always presents the same cross section.

I next assumed the boat to be sailing 31 degrees off the apparent wind and 45 degrees off the true wind; angle of attack of the sail on the apparent wind was taken as 10 degrees. Following the rationale set forth by Juan Baader in his The Sailing Yacht, it turns out that the foregoing conditions equate to a resultant wind force per unit of sail area, P_u, as given in the following: $P_u = 0.0028\ v^2$, where P_u is expressed in pounds per square foot and v must be entered in feet per second of true wind.

Next came the selection of mast and sail parameters; these were maintained in general terms in order to obtain expressions of general application. The sail was postulated as triangular with a luff of length L, aspect ratio A; accordingly, the sail area S was then equal to L^2/A and, incidentally, the foot then measures $2L/A$. The height of the mast is represented by the quantity $L + \ell$, where ℓ is the distance of the sail (foot) above the deck.

In expressions to follow, x will represent positions along the mast with the origin taken at the masthead; the base of the mast, therefore, is at $x = L + \ell$. The luff is continuously bent onto the mast for its entire length L.

The shear force along the mast resulting from the above arrangement and wind force loading calculates to be: $P_x = (P_u/A)x^2$, from $x = 0$ to $x = L$. It is then constant, and: $P_x = (P_u/A)L^2$, from $x = 0$ to $x = L + \ell$. These expressions permit a shear force diagram to be drawn, the integration of the area of which yields bending moment expressions: $M_x = (P_u/3A)x^3$, between $x = 0$ and $x = L$ while $M_x = (P_u/A)L^2\ (L/3) + x - L$, between $x = L$ and $x = L + \ell$. The two expressions immediately above state the bending moment in foot pounds as a function of position along the mast, imposed upon the mast by the wind force. L, and x must be expressed in feet.

Having now described what is going on external to the mast, we need to do the same thing for the events internal to the mast. The line of attack is that the moments generated internally oppose and balance those imposed externally ... otherwise the mast would rotate.

The internally generated moment as a function of position was derived. Its expression is: $M_{ix} = (\pi/4)r_x^3N_m$, where M_{ix} is in pound-inches, r in inches and N_m in pounds per square inch. The factor $\pi r_x^3/4$ in the foregoing expression is what is known as the Section Modulus, S_{mod}. Accordingly: $M_{ix} = S_{modx}N_m$ & I_xN_m/r_x, since $S_{mod} = I/r$. "I" is the moment of inertia of a section. These things are mentioned in case someone is looking to see where things like Section Modulus and Moment of Inertia enter the picture.

As stated previously, $M_x(12) = M_{ix}$. The factor (12) is entered in order to place M_x into terms of inch-pounds so that the external moment at position x may be equated to the internal moment at position x. Equating the internal and the external moments yields the following: $(12)P_ux^3/3A = \pi r_x^3N_m/4$, in the region $x = 0$ to $x = L$. From this it follows that $r_x = (2P_u/\pi N_mA)^{1/3}(2x)$; while in the region $x = L$ to $x = L + \ell$ the formula becomes: $R_x = \left[(48P_u L^2/\pi N_m A)(L/3) + x - L\right]^{1/3}$.

In order to solve for r_x expressed above, a few more assumptions and agreements are necessary. First of all, I will not enter a factor of safety; instead, I will base the calculations on a true wind velocity of 30 knots (50 feet per second), provided the reader promises to shorten sail before the wind pipes up to 30 knots. For this wind velocity, P_u then becomes 7 pounds per square foot. Also, let us work with a large mast where $L + \ell = 60'$ and $\ell = 3'$. I select A = 6 (Aspect Ratio) because I might want to put two of these masts and sails on the same boat a la Jerry Milgram's CASCADE. The maximum fiber stress for a spruce mast is set at 5,000 pounds per square inch. We can now use the above equations for r_x to obtain mast radii. Mast radii at the gooseneck and at the deck respectively are: $r_L = 6.04"$ and $R_{L+\ell} = 6.34"$.

For the size of craft we have obviously contemplated, the figures didn't turn out bad at all. But what about the shape of the mast above the gooseneck? Look again at the expression for r_x in this region. Note that r_x is directly proportional to x. This means that a straight taper is indicated for the length L and that the radius at the masthead goes to zero. This comes as somewhat of a surprise, but is a consequence of the cross section selected and the manner of loading via the triangular sail, as well as requiring a constant stress in the skin of N_m.

In case the point was missed, it is significant to note that the mast is a "Fully Stressed" structure, i.e., the outer fiber stress is a constant along its entire length. The characteristic of a fully stressed structure is that it represents a minimum requirement in material, hence, minimum weight. (Weight of the above mast in spruce would be about 477 pounds.)

I believe that it has been shown that a solid, free-standing mast is feasible: its sizing is not too untoward and it will stand up to the imposed forces. What has not been shown is its practicality or idiosyncracies it might exhibit in use. For example, we know that we would have to modify the mast in its upper portions to maintain some minimum diameter; you've got to have some substance to lay a track on. However, there is an even larger and more important question: What deflections would the mast experience and what effect would this have on the performance of the sail? (Anyone in the audience care to take up this problem?) Having nevertheless proved what I intended to, I sign off with one last question: What single factor, more than any other, affects the strength of a mast? It was not taken into account above.

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A 2,000 A.D. YACHT, by John Morwood; Woodacres; Hythe, Kent, England.

"Before you sail," said Gerald, "Come and see how they are built." I nodded my head to the lovely Trishy who looks after me to indicate we should follow him. She pushed my chair along after the tall and upright figure of Gerald. He was still active but not walking very fast.

The factory was small because they only made the 52 footer there. Looking through the door, I saw a huge shape of a boat with rounded decks and, when I got inside, I found that this boat shape was suspended above the floor by two fore and aft axles, one at the bow and the other at the stern. At the side of the hull was a track alongside the boat on which were trolleys with glass cloth and PVC foam.

"You see, my dear," said Gerald, addressing Trishy, "The boat is made by a revolutionary process." Then, "Wake up, John."

"I wasn't asleep," I said, "and anyway, you were not talking to me. What did you say?"

"I was just explaining how the boat was twisted on her long axis and the glass cloth and narrow strips of PVC foam were wound on like the core of lavatory paper. We can now build a hull in half an hour."

"Ah, the lavatory! Every boat should have one," I said.

"John, you old fool; I was telling Trishy how we built the hulls in half an hour by revolving them,"

"Nothing revolutionary in that," said I. "You invented it a quarter of a century ago.. Oh, I see. It was one of your idiotic puns."

They were just starting to make a hull. The end of a roll of glass cloth was attached to the stern; the boat began to turn; and in next to no time, the hull had been covered with glass. On its way to the boat, the cloth dipped into a trough of resin.

Next, the foam strip was wound on, dripping surplus resin to the floor. Finally, the outside layers of glass cloth were wound on under some tension to get air bubbles out. The hull was complete.

After that, a tent was dropped from the roof and the heaters turned on, and the hull was left to cure. After curing, the hull is cut around its middle and taken off the mold. The two halves are filled with furniture and joined together again. Then outside fittings are added, and the hull is complete except for painting. Each boat is completed in one day.

We didn't wait to all all that, however, as we had come for a sail in the demonstration boat, the first of a new series. Besides, I thought that Gerald was paying too much attention to my little girl. My dishy Trishy was far too precious to me to be ogled by that Octagenarian Lothario.

Trishy pushed me along to the quayside where the boat lay. It looked a bit like a modified Thamas barge because of what appeared to be leeboards. Somehow, bless her, Trishy got me up the gangplank and along to the wheelhouse - just forward of the foremast. There, she got me into the driving seat, and she and Gerald also came in. Fortunately, the seat was only wide enough for two, so Gerald had to sit on the pilot berth opposite, leaving Trishy and me together.

The wind was blowing off the quay. We had running lines to fore and aft bollards, and these were slackened to let us lie about 25 feet off. I pressed the foil control, and the compressed air motor sent the foils out to their full span and locked them.

The rig of this version was the brigantine with semi-elliptical sails on both masts. The foresail was set square-rigged while the mizzen was an ingenious lugsail. No jibs were carried.

The air motor was again set in motion to raise the sails while the onboard ends of the running lines were let go and reeled in after buzzing around the bollards.

We were sailing.

Quickly picking up way, we sped along modestly at 15 knots in a wind of 6 knots. We sailed bolt upright because this was the cruising version with both foils in the water at all times. We creamed out into the estuary and went looking for wind. The best we could get was Force Four (20 knots) which gave us our top speed of 28 knots. Some claims for greater speeds have been made, but I rather doubt them.

The wind then fell lighter and speeds dropped again. By this time, we were well out to sea. The boat steered herself nicely without needing any vane or electrical gears and needed no attention. Gerald and Trishy were keeping a good lookout for shipping.

It was all tremendous. She was a great boat to sail. I thought of all the work and research which had gone into the foils and the great pioneers like Forlanini, van Schertel, McIntyre and, perhaps the greatest of them all: Edmond Bruce. I thought of all the effort and inventiveness needed to get the semi-elliptical sails working from George Dibb onward. This was the greatest sailing efficiency possible.

Finally, I remembered Gerald's model experiments and his excitement when he found his foils working. Then came his hull construction method which has made such superb yachts available to so many people - though it does overcrowd the marinas and seas a bit. I was happy to have lived such an exciting life.

I must have dozed off in my pleasant nostalgia. When I awaked, we were right out of sight of land - the boat still steadily maintaining course. I looked at my watch. We had only crossed the bar one hour before and were now heading out into the Atlantic. Trishy was handing me a cup of tea. Gerald was looking at the chart.

"Thank you my dear. What a lovely afternoon it has been."

Gerald looked up from the chart. "I think the best thing to do is to put her on a reciprocal course for an hour. That should take us back where we came from".

"Silly old idiot," I thought to myself. "He hasn't an idea where we are - but neither have I."

Suddenly, I saw it - an ear-ring in Gerald's beard. He had been at it again with Trishy. Some people have all the luck. But, I had a good afternoon, too.

Editor's Note: Gerald Holtom's "Foilers" are now, in 1976, being manufactured by his "roll around" method. They should mean some cheap, fast sailing. His address is 5, Hillside Street; Hythe, Kent, England.

DAGGERBOARD and RUDDER AIRFOIL SHAPES.

Letter from: A.M.Van Spanje; P.O. Box 70; Philipsburg, St. Maarten, Netherlands Antilles; West Indies.

Dear Jack,

AYRS AIRS 10 contained a very interesting article by David Booth on: "Theory of Rudders." Aerodynamics can be used for behavioral studies of rudders and daggerboards if the differences between hydro- and aero-dynamic laws are not forgotten. This has already influenced the shape of rudders. Where before, a falling water drop was thought to be the ultimate in efficiency for least resistance in water or air, we know now that the lift generated by the airfoil shape is more important. Already in the 17th Century, the flat and round bottom boats had leeboards with airfoil shapes - of low aspect ratio for work on lakes and high aspect ratio for deep water sailing. Moreover, they were flat or even slightly hollowed on the outside and convex on the inside. Therefore, they not only countered drift in these keel-less boats but also created lift to windward.

The cross-section of a modern rudder or daggerboard shows the greatest camber to be on or just aft of mid-chord as in the modern aircraft wing. Applied to the daggerboards of a catamaran, I feel however, that the example of the leeboards should be applied but in reverse to obtain the greatest benefit. It is the windward board of a catamaran that should do the work, although the leeboard can help. But, in heavy weather the lee board assists in capsizing.

My question now is to ask your opinion on my idea that in catamarans the daggerboards should have an airfoil shape with the flat side towards the centre line of the boat and the convex side outward. This, of course, requires that only the weather board be used except when running,

Sincerely, A.M. Van Spanje

Dear Mr. Van Spanje,

I agree completely with you on using aerodynamic methods to attack the problems of hydrofoils as rudders, keels and leeboards. The greatest thickness of symmetrical foils as used in rudder-skegs, keels and boards is usually about 25 to 35% of the chord length aft of the nose which should be rounded. A line connecting these points is called the quarter chord line, and its angle to the vertical is what we term the sweep angle. Some research studies at the Davidson Laboratory of Stevens Institute of Technology on keels showed for the hull form used:

All Data for Optimum Condition - Least Resistance.

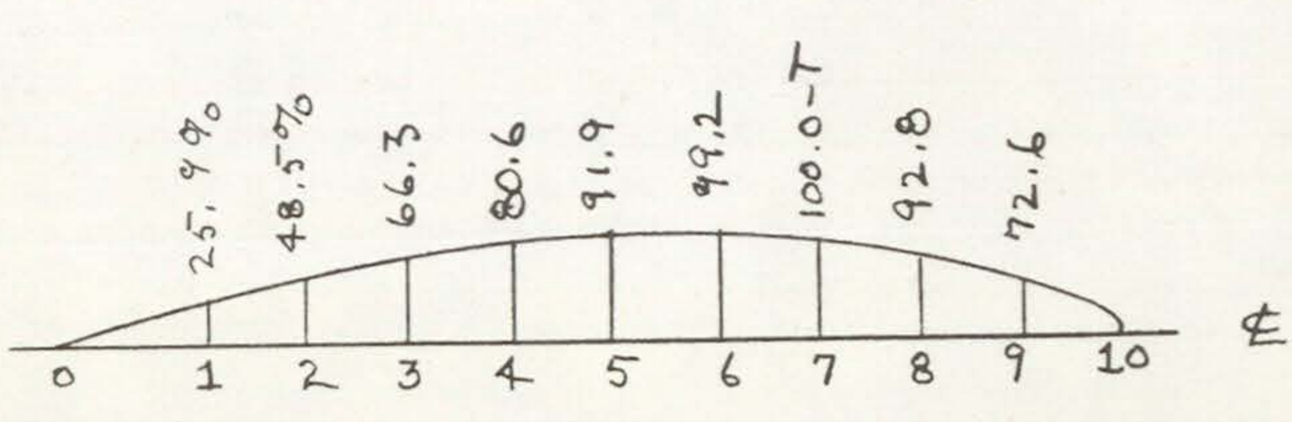
Sweep Angle:	50	25	0
Aspect Ratio:	.573	.855	1.52

From AYRS FCCG 2, if we manipulate Edmond Bruce's equations from AYRS 66,42 and also reproduced in AYRS 82, the maximum area of a centerboard should be in square feet = $0.047\ W^{2/3}$ where W is the weight of the boat, crew and all gear in pounds.

A good foil shape for rudders, keels and boards is shown in the sketch as a half-section symmetrical about the centreline. I suppose cutting it down the centreline would produce a good asymmetric shape. Thickness at each of ten equally - spaced stations is given as a percentage of the maximum thickness: "T".

(The following figure is reproduced with permission from the Yacht Design Institute Brewer and Wallstrom Associates.)

Sincerely, Jack Shortall



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DRAG ANGLES - Part III, by Henry A Morss, Jr.; 6 Ballast Lane, Marblehead, Ma 01945.
A PRACTICAL PROGRAM FOR THE SKIPPER.

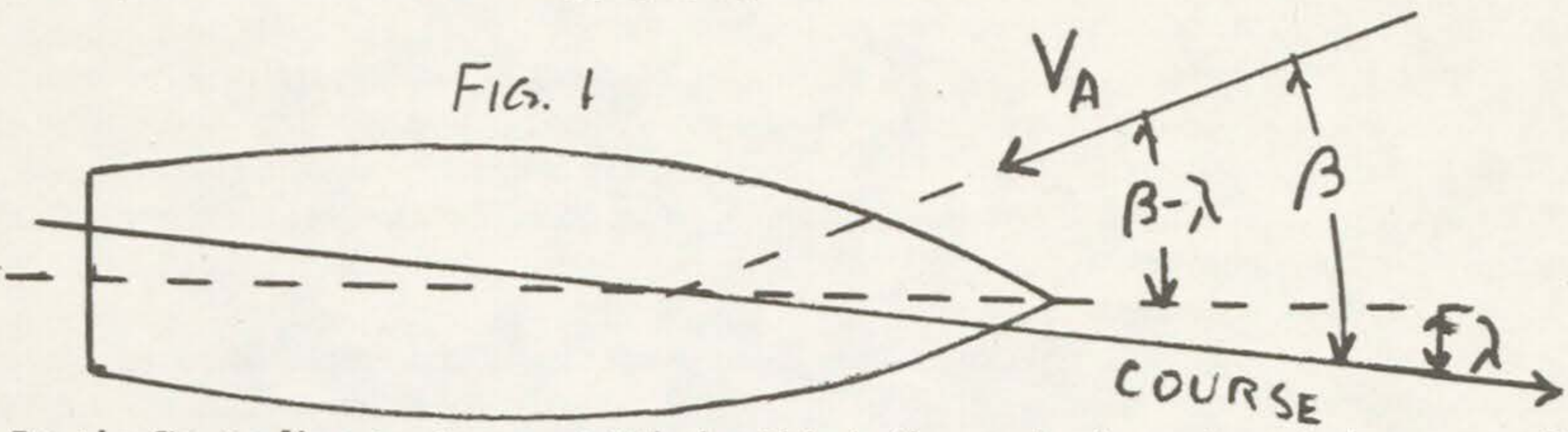
The first two articles in this series defined the drag angles, explained their importance and value to sailors, and described means for determining values. Unhappily very few actual values have been reported and very little is known of them. It would be helpful if numerous individuals would determine and report values for their own boats.

The most practical program for the man who is interested in this and willing to put time and effort into it seems to be in two primary parts: 1) Set up for and measure beta on many points of sailing in varying conditions of wind and sea. 2) By the "tethered boat test," measure the sail drag angles over the range of trim and combination of sails.

With beta and $_S$ known, $_H$ is found from the equation $= G_S + G_H$, the Course Theorem.

Here is more detail for carrying out the program:

Beta. By definition, beta is the angle between the boat's course and the apparent wind. In the actual business of measuring beta, one will normally measure two angles and add them together. One is the angle between the boat's centerline and the apparent wind; the other is the leeway angle.



Boat's Centerline to Apparent Wind. This is the angle shown by wind vanes. Since many boats nowadays carry wind vanes with electronic indicators handy to the helmsman, their skippers have a good start.

This is not something to take casually. Rather precise values are needed, or the usefulness of the results will be small. Extra effort put into calibration is well worth while when one wants to do accurate work.

Presumably the sensor - the vane itself - should be above the top of the mast. Locations below that can hardly be far enough away from the sails to be in clear wind, unaffected by the sails.

There is a strong argument to say that the top of the mast is not the right place for wind instruments. They ought to be at the height of the center of effort of the sails, as the best practical compromise of the "wind shear," the variation of wind strength with height above the water. Because of this variation, the direction of the apparent wind also varies with height, even if the direction of the true wind does not.

Edmond Bruce sometimes put wind instruments on a greatly elongated spreader out to windward of the mast - one way to get the proper height. This is awkward and useful on only one tack (unless it is moved or duplicated). I never tried it, because I didn't see how to be sure of the location of the zero of the instrument, one of the problems of calibration.

At times I have tackled this problem with an extra "mast" of the appropriate height mounted at the bow and sloping out forward to put the instruments as far in front of the luff of the jib as was practical.

Leeway Angle. This ought to be easy, but I have never found it so. The reason, as with the angle between the boat's centerline and the apparent wind, is the need for rather precise results.

Some people have done pretty well by marking angles on the deck, then sighting the wake. That has never satisfied me, perhaps because I am not a steady enough helmsman.

Towing some object 50 to 100 feet astern in the water and observing the angle of the towing cord is not satisfactory unless the cord is attached at the waterline. If it is fastened at the level of the deck, the wind will often put a curve into it and distort the reading, I abandoned that idea years ago.

I have had best luck with a "water vane" on a rigid arm mounted over the bow on a vertical axis. (Fig. 2). This puts the sensor out in clear water, unaffected by the hull. Unfortunately, the rigid arm cannot be very long. Therefore the vane responds to every passing wave. Visual averaging can do pretty well in reducing such variations. For the person so inclined, electrical averaging (with adjustable time constant?) can be advantageous. (See Fig. 2 on Page 2.)

The Measurement of $_s$. As was pointed out in the preceding articale, Edmond Bruce's "tethered boat test" is the convenient method. The skipper can usually carry it out at his own mooring with or without assistance.

A detailed description of one way to do this was given in the original reference (AYRS 40, "The Physics of Sailing Craft as Revealed by Measurements at Full Size" (Reprinted in AYRS 82, 12). Figures taken from these references are also printed in our Journal 83A.

The wind vane described above will be used for another purpose. The only other measurement needed will be the angle between the "tethering line" and the centerline of the boat. The skipper can work out a way to do that. Again, care and accuracy are important.

In his drawing, Bruce shows the "tethering line" fastened directly to the rail of the boat. In his later work he found some advantage in using a bridle between that line and the boat. The boat is steadier and adjustment is easier.

Some readers may note that I did not call for making these readings over a range of wind strengths. Probably that is not necessary. Surely it is not for measurements of the force, which follow the square law closely (sail force proportional to square of apparent wind strength. The drag angle is probably not exactly constant through varying wind strengths, but nearly so. It would be reassuring if someone would test this one day and give us a definite answer.

Reporting Results. Perhaps the main thing to emphasize is the importance of a complete factual description. Among other things, this should include details of the methods used to calibrate the instruments and an estimate of the accuracy of each measurement and of the final results. If and as other data become available, comparisons may be in order.

Our good editor might be prevailed upon to publish such reports.

Summary. As I have said, there is a need for more reliable values of drag angles. This requires careful and time-consuming work but is a reasonable undertaking for a careful experimenter. It can be very satisfying. All this is an aspect of sailing of which few people have ever thought. Some of us have had a lot of fun with this more scientific approach to sailing.

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MATERIALS & BOAT BUILDING

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POLYNESIAN CATAMARAN UNDER CONSTRUCTION.

Letter from: Don Woods; 1123 Astor Ave. S.W.; Atlanta, Ga 30310.

Dear Jack,

My big boat is set aside for now, but it will be completed. I did finish a small catamaran this winter and am enclosing a picture of one hull taken earlier. Both hulls are completed and all that remains is the rigging. It will be rigged strictly polynesian with two 60 sq. ft. (5.6 sq. m) Tahitian type sails as copied from the book; Canoes of Oceania. The hulls are quite simple to construct, but there was a good bit of engineering in the bottom shape.

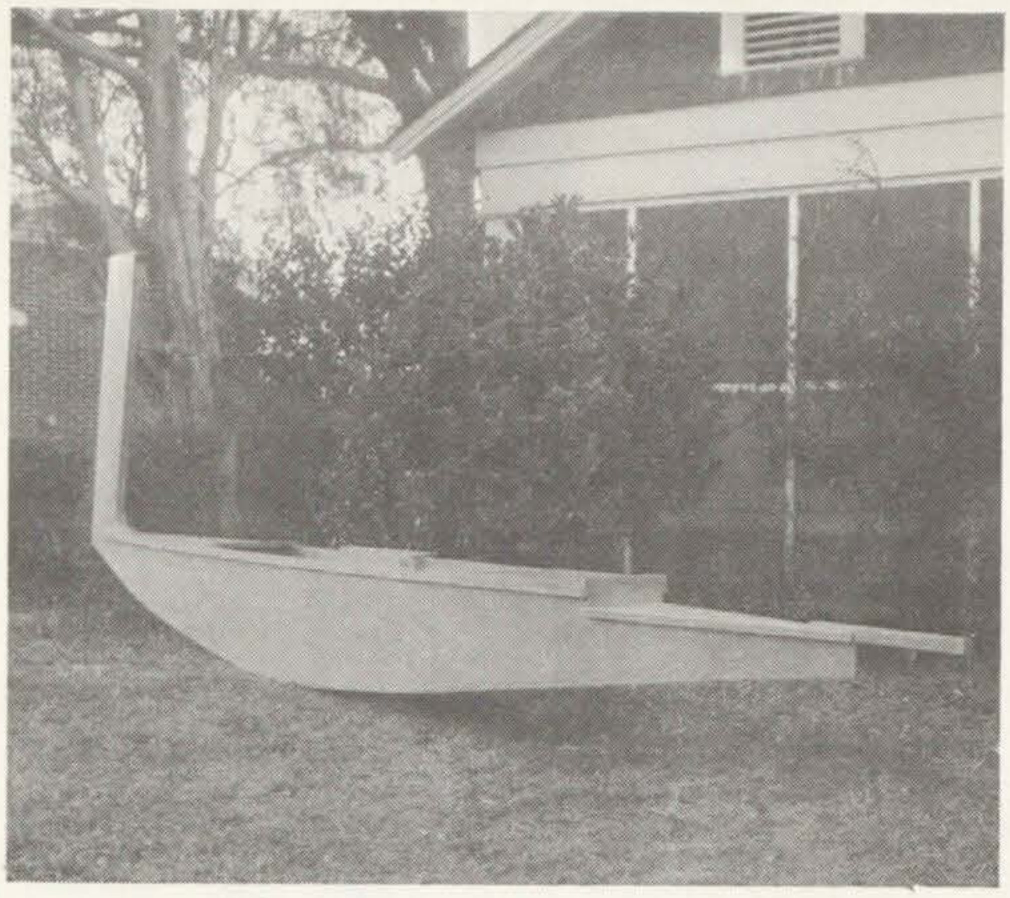
My catamaran is 16 1/2 ft. long (5.0 m), 7 ft. 10 in. beam (2.4 m), hull beam 18 in. (38 cm), has seats in each hull and plenty of room for beer coolers in the hulls. The stern posts are a bit over 5 feet (1.5 m) off the water at their tops. I read somewhere that the sternposts and the gourds at the top of all ancient Polynesian masts were religious symbols. Evidently the writer of such had never tried to right a capsized catamaran.

It is built with WEST System epoxy on plywood and all glue is epoxy. Fasteners are bronze boat nails. I have a good supplier for the latter who sells them at $2.00 (1.00) per pound if anyone is interested.

Canoes of Oceania, the masterpiece book on Polynesian boats, is again available thur the Bishop Museum Press in Honolulu. It is $25.00 (12.50) but worth every penny.

Sincerely, Don Woods

(See photo - top of page 43.)



WING MAST DESIGN FOR CRUISING CATAMARAN.

Letter from: Conrad Muller; P. O. Box 5352; Charleston, OR 97420.

The enclosed drawing is my inspiration for a wing sail. On our boat (See AYRS 83A, p. 20), the mast will be round, 6 in. (8.5 cm) in diameter and 30 ft. long (9.1 m). I am planning to let the sail slide around a non-rotating mast. I may need to go to a rotating mast, but I hope not. (See Drawing on back cover.)

My bilges will be used for storage, and from experience abrasion therein can and does take place. Even worse, people drop things as cans, tools, spare anchors, etc. If I were not going to use the bilges for this kind of stowage, I would not bother with fabric.

Sincerely, Conrad Muller

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AYRS FLORIDA-CARIBBEAN CONTACT GROUP

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The AYRS-FCCG is composed of 117 AYRS Members having a sailing interest in southern waters including the Caribbean Sea and the Gulf of Mexico. Although we have AYRS-FCCG Members from the western U.S., middle west and New England, most live in the southeast U.S. from Maryland-Virginia to Florida to Texas and on islands and countries in the Caribbean. An annual fee of $2.00 is requested from those wishing to take part in our activities or contribute to same. Write the Editor.

SAILING MEETING NO. 3 - May 15 and 16, 1976.

Location: At the home of: Warren Noden; 331 Palermo Circle; Fort Myers Beach, Fl. 33931. Tel: (813) 463-9547.

AYRS Members and those interested in our organization are invited to SM-3. Warren has a waterfront home with dockage, and Members are encouraged to sail or trail their boats here and bring models. We will have movies of the John Player's world speed trials and of David Keiper's flying hydrofoil cruising trimaran.

WORLD MULTIHULL SYMPOSIUM - June 14-17, 1976 - Toronto, Canada.

Write for details to Charles Chiodi, Editor, "MULTIHULLS MAGAZINE," 91 Newbury Ave., No. Quincy, MA 02171. Let the Editor know if you are interested in group air travel from Florida to the meeting at extra-low rates.

FLORIDA $50 REGATTAS.

AYRS Member Leland Hardy; 4426 Leola Lane; Orlando, FL 32806; Tel: (305) 277-0319. has volunteered to handle the details of our first Florida $50 Regatta at SM-3 in emulation of the Texas series. I hope that Members in this area will continue to design and build $50 boats so that we can continue to hold competitions. Any time we can get three or more boats in the water, we will be happy to hold a race at some convenient location. Write Leland for details.

AYRS SAILING YACHT RESEARCH CENTER: SYRC.

Member Thomas Hooper; P.O. Box 447; Tuskegee, ALA 36083 has taken as his master's thesis the design of the AYRS SYRC. Write Tom if you have any suggestions or advice. We will publish the final design.

AMATEUR YACHT RESEARCH SOCIETY
John W. Shortall III - AYRS Editor
10822 92nd Avenue North
Seminole, Florida 33542 U.S.A.

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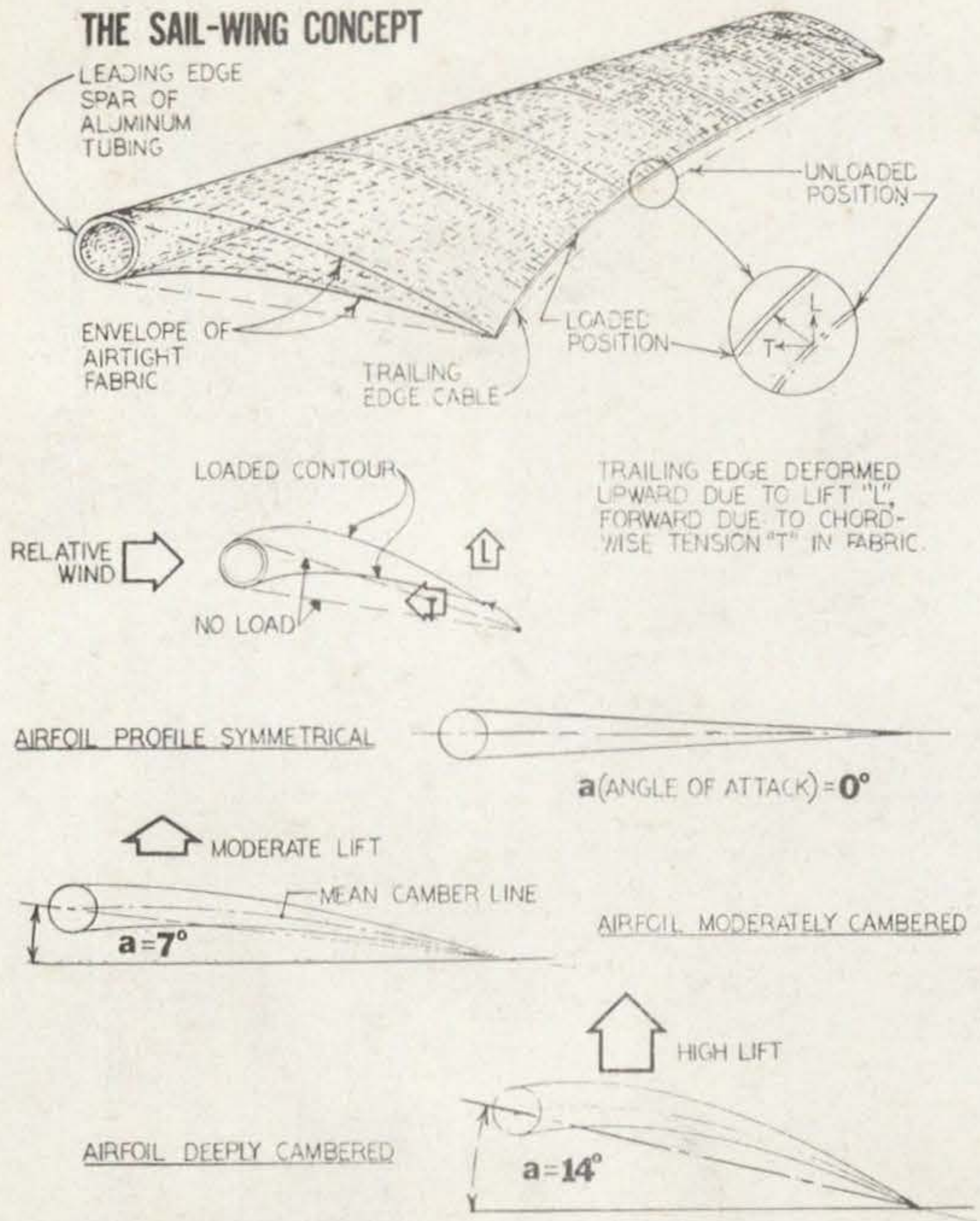
AYRS 84A

THE SAIL-WING CONCEPT



RESPONSE OF SAILWING TO CHANGES IN ANGLE OF ATTACK

(See Wing Mast Article - Page 43.)

TO»