(Cont'd from Page 47).
age with comments on the capsize of *GULFSTREAMER* plus the tape of Mark Hassall's hurricane experience as later published in the book: *Love for Sail* by Mark Hassall and Jim Brown. Among the many from out-of-state were: Doran, Dyck, Gougeon, Leonard, Morss, Rodriguez, Stoddart and Stover. My thanks to all the 23 members of the working group who helped make this work and especially Tom Baldwin, Raymond Brown, Leland Hardy and the hardworking group at the front desk which included my wife Claire.

Many suggested making this an annual event, but such will depend on an AYRS Member volunteering to coordinate such. *Any offers?*

(*See Page 5 for other Sailing Meeting notes.*)

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

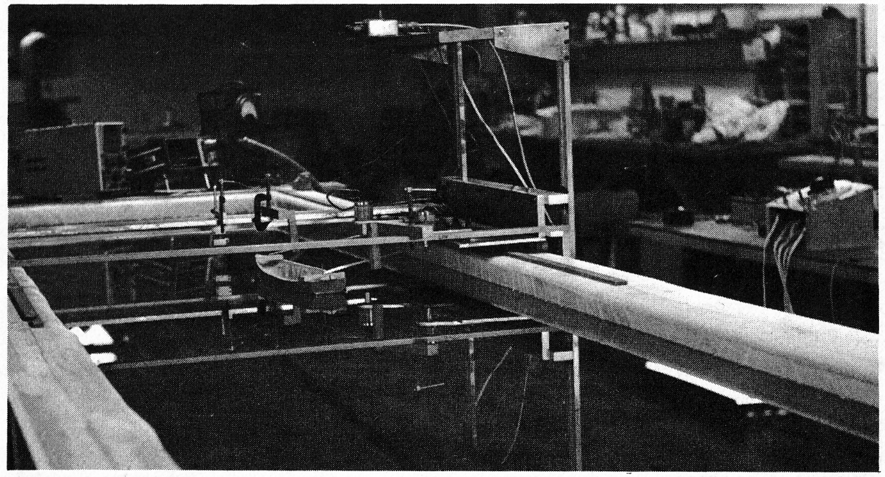
TO»

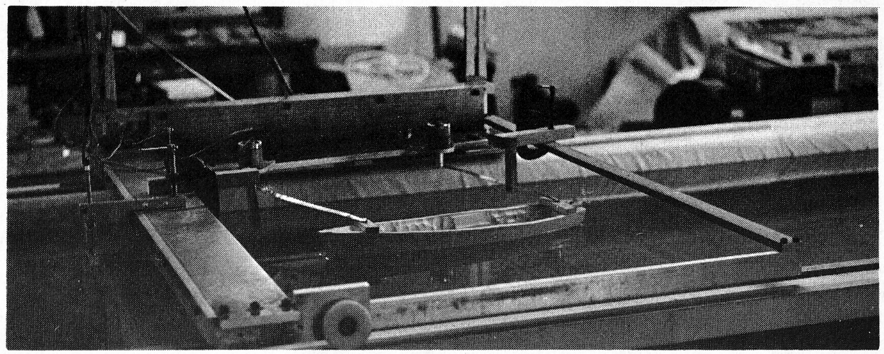
AYRS

AYRS HULL RESEARCH '76

JOURNAL 84B
JULY, 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





Figures 14 & 15 from: A Lift Study of Some Sailing Hulls by John H. Thompson. See Page 6.

A LIFT STUDY OF SOME SAILING HULLS -
FIVE YEARS WITH A BRUCE TANK.
WHIFFLETREE RESEARCH AND TESTING
RE-CIRCULATION TEST TANK DESIGN
APPLICATION OF HYDROFOILS TO SAILING CRAFT
DRAG ANGLES AND SAILING PERFORMANCE

THE AMATEUR YACHT RESEARCH SOCIETY

(Founded, June, 1955 to encourage Amateur and Individual Yacht Research.)

Founder and Consultant Editor: John Morwood, Woodacres, Hythe, Kent.
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CONTENTS

Note to Authors: While we always welcome letters and articles for publication in any form, it helps the Editor when such can be sent in two copies, double-spaced typing. Units should be consistent with those used in the AYRS publications. We are short of articles and letters on: long distance cruising and materials and boatbuilding, and welcome such. Please remember that we will not print articles of the types usually published in existing yachting magazines. AYRS is concerned with YACHTS and RESEARCH.

For those who would like to know which Wharram Cat I'm building, *KAUAMEA* is the Tangaroa design, the smallest of the ocean cruisers; and to me the largest to be safely sailed single handed. She is 34 feet OA, 28 feet LWL, with each hull having a beam of 5 feet 6 inches and an overall beam of 16 feet 6 inches. She will become my home from the instant of her launching. Hopefully, she will be comfortable enough to provide feeding and housing for me and my beloved Schwinn Traveler 10-speed bicycle.

Granted *KAUAMEA* is not everybody's ideal vessel. A man's taste in boats is as varied as his taste in women. You may be partial to the well-stacked, well-built, full-bodied type whereas I like my women tall, lean, long-legged and loaded with sin. The oceans are wide enough to take every man's kind of boat. The problem arises only when we all try to rush back to land.

AYRS FLORIDA-CARIBBEAN CONTACT GROUP

The AYRS-FCCG is a sub-group of the International AYRS and is composed of 135 Members having a sailing interest in southern waters including the Caribbean Sea, the Gulf of Mexico, and the Mid-Atlantic Ocean Area. Although there are some 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 and on the Caribbean. An annual fee of $2.00 is requested from those wishing to take part in our activities and receive bulletins on same. Please contact the Editor for any further information desired.

SAILING MEETING NO. 2 - TEXAS.

On April 24, 1976, a total of 17 boats were entered in the annual $50 Regatta which was won by Ed Doran's sailing raft.

SAILING MEETING NO. 3 - FLORIDA.

On May 15 and 16, 1976, 175 participants gathered to hear and take part in six panel discussions on: Advanced Materials and Boatbuilding (WEST, C-FLEX, Foam, etc.); Long Distance Cruising; Heavy Weather Sailing; Long Distance Cruising for Women; Yacht Research and Design for High Speed Sailing; and Multihulls including the capsize problem. Gordon Gillett gave a demonstration of flying up to six kite sails simultaneously and a lecture on same. A number of members brought model yachts and slides, and the film showing included recent pictures of Dave Keiper's *WILLIWAW* flying hydrofoil cruising trimaran now in New Zealand. Three boats entered the $50 Regatta and only one finished. The Editor's boat, built jointly with Bruce DuClos and sailed by Bruce's pretty wife Penny, suffered mast failure from her free-standing bamboo stick as recommended by Ed Mahinske in AYRS 83B. She used a semi-elliptical sail (AYRS 81) which was named: *MORS'L* after: Morwood Sail. Bob Bowers' Pensacola boat was well-built with a clear plastic sail and expertly handled. Rudder failure cost her first place. Winner was an entry from a local newspaper. Exhibits included: Hydrovane Self Steering, RVG Self Steering, and Trikini Trimarans. Winds up to 75 mph reduced the number of yachts docked at SM-3 and lent added realism to the heavy weather sailing panel. Jim Brown sent a taped mess-

(Cont'd on back cover.)

Sad to say there is an undercurrent of snobbishness by trimaran owners over Polynesian Catamaran type of vessels. It is not as open as the downright hostility of some monohull owners. But it is there. Now that trimarans are easily going for a thousand dollars a foot there seems to be another element to look down upon. I'm certain the oceans have been crossed by as many two hundred dollar a foot (and less) vessels as one thousand dollar a foot vessels.

Besides taking slides of each step of progress I keep a running record of building costs. But at this time I have no total, and won't until the boat is finished. But I'd say I've got about $3,000 in her. I always try to keep my buying of materials at least one or two steps ahead of my building. Since each step in building always takes three times longer than I estimate my building hasn't run over my buying as yet. At this stage in building I have the hulls complete and fiberglassed, the inside furniture in place, and the stringers ready for decking. In my buying stage I'm in the fun part; lanterns, running lights, rigging, stove, etc. All from fishing supply outlets through the place where I work.

I'd like to say something about this running record that might help somebody else thinking of building. The construction of a boat, or anything else I guess, is a series of small steps, none of which should be judged in itself. If you start worrying over the slight curve you see in the keel, or a gap between laminations, or a multitude of many other small mistakes, I guarantee the vessel will never float on water because you will never finish it. The think you have to do is tell yourself that you will only pass judgement on the completed project. Until it is finished it is nothing. It doesn't exist. Only when you stand back and say to yourself it is finished can you also say it is a good boat or it is a not-so-good boat.

You think I don't get discouraged? On one side of me I've got a neighbor who is an expert on everything. And likes to say so. He has verbally destroyed my boat at almost every stage of construction. His favorite expression is to squint along the lines and then just walk away shaking his head and muttering about how it is much worse than he expected. On the other side of me I've got a religious sect who meet four times a week and think the Lord has a hearing problem. When I first started building the young girls of the sect used to stand and watch asking girl-type questions. That was until they learned the floods were coming and I was building an ark. Now the girls are kept in the church behind closed doors.

Naturally since I work for a living I don't spend as much time building as I would like. Mostly I boat-build on weekends, which makes me somewhat of a social zero. Had a steady girl for awhile who liked to sit and and watch, but she got bored and headed for more exciting pastures. Like Tom Colvin says, little girls grow up playing house, not boat. They like grass and plants and fences. But if I were to build again I wouldn't try to do it while holding down a full time job. I would consider living money as important to save as wood buying money. I started construction in June of 1974. Hopefully she will be launched next summer or early fall (1976). But, if I had built full-time, I would have been done a year ago.

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.

AYRS, Americas has been constituted to assist in the editing and publishing of books for the worldwide membership and works in close cooperation with and reports to the AYRS Committee and Administrator in England.

FUTURE ISSUES OF AYRS JOURNAL: Materials are on hand for the following upcoming issues of our bi-monthly Journal: Advanced Materials and Boatbuilding; Long Distance Cruising; Long Distance Cruising for Women; Design for High Speed Sailing; Hydrofoils; Heavy Weather Cruising; Multihull Capsize; and Kite Sails. We are also assembling a technical number to include hull lines drawings; polar diagrams; and stability curves, among others, to gather in one place information of this kind. *If any have articles letters or questions on these, we would welcome same.* Although the Journal issues will be topical, we will include letters and articles on other themes, and our *Florida-Caribbean Contact Group* will continue to have its own section.

OTHER AYRS CONTACT GROUPS? With 135 Members and three sailing meetings already held, the *AYRS-FCCG* is enthusiastically supported. *Would not some AYRS Members offer to create these in other parts of the U.S. and Canada and in other countries?* We can supply names and addresses for regions in this hemisphere, and Michael Ellison can do the same for other parts of the world.

JOURNAL QUALITY: To answer some comments, we would dearly like to improve the quality of paper and type in the new AYRS Journal, but at this time we just cannot afford to do so. Please bear with us until the membership increases. At this date, we have added some 200 new members in the U.S. alone. Our goal is another 600 by September, 1977, at which time we will be in much better financial shape.

APPRECIATION: The Advisory Committee of AYRS, Americas voted a resolution of thanks to Leland Hardy, Dick Kelting, and Warren Noden for their help to which I would like to add my personal gratitude.

STUDENT MEMBERSHIP: A number of university students have joined the AYRS recently in response to the decision to reduce membership fees for such to $10 for a maximum of two years. We want to increase this type of member and believe many more students would join AYRS *if they learned* *such a group exists and what it does. Could those AYRS Members with access to universities and colleges please help spread the word on this?*

HELP! Several have volunteered to assist AYRS, Americas in our publishing and membership efforts, *but we still need more help*, if we are to continue this experiment. In response to many, many requests, we are requesting that the AYRS Committee in England approve our assuming the administrative details for AYRS Members in this hemisphere, grant monies for such and go on an invoicing system of billing. We may have to employ part-time secretaries to do this instead of using our meager funds for publishing. In addition, we still need more help in *Dallas* and *Florida* as well as *others* in the *U.S.*, *Canada*, *Caribbean* and *South and Central America*.

NON PROFIT STATUS. The Internal Revenue Service has granted approval to AYRS, Americas as a non-profit, tax ememept scientific foundation. This approval will enable our organization to obtain donated land, buildings and facilities for an AYRS, Americas Headquarters and perhaps a Sailing Yacht Research Center. A Florida AYRS Member has advised of the availability of a high speed digital computer to be offered to a non-profit group and has volunteered to supply space for same. This would make it possible for any AYRS Member willing to purchase a terminal to communicate with and use the computer by telephone from anywhere in this hemisphere.

TECHNICAL JOURNAL ISSUE? One of our Members has suggested that one entire issue of our Journal be devoted to publishing polar curves of yacht performance, hull lines drawings, stability curves and similar data. I will volunteer my own designs to this, and AYRS Member Jay Benford has a number of stability curves he will allow us to print. I would welcome receipt of material for such an issue which could provide us with some good experimental and analytical data on which to base ongoing theoretical studies for *both single- and multi-hulls*.

MULTIHULL CAPSIZE: It has been suggested by some that the AYRS take a position on this matter, as it was primarily the AYRS in the early days which encouraged and fostered the development of catamarans, proas, and trimarans. Although there is a paucity of data, I have information here on the following six recent accidents involving multihulls. I would be glad to prepare an article on the subject or ask someone else to do this *if* AYRS Members would send me detailed accounts on each of these and any additional incidents with the exception of *MERIDIAN*.

1. *GREAT BRITAIN III* - 80 ft. trimaran. Capsize about February, 1976.
2. *TRIPLE ARROW* - About December, 1975, this 43 ft. trimaran was found capsized with no-one aboard. She was being single-handed at high speed, and the best guess is the skipper was lost overboard. The boat could then have sailed on for many miles under self-steering. See SAIL Magazine for June, 1976, p. 8.
3. *MERIDIAN* - 35 ft. trimaran capsized June, 1975, in storm which sunk two keel boats. Crew lived for 16 days in inverted hull. See MULTIHULLS Magazine for excellent articles by Jim Brown: Fall '75, Winter '76, and Spring '76 issues.
   (This was not a Brown-designed trimaran.)
4. *LILLIAN* - This 55 ft. proa capsized about October, 1975.

When fiberglassing the hulls I could not use the accepted methods of brush or roller. It just didn't work for me. My hulls were lying on their sides when I glassed so I was working on a horizontal surface. What I did was staple the glass down with bronze staples. Then I mixed up a batch of resin and poured it over the glass. With a rubber squeegee I worked fast as hell to get it all spread out. It took three batches for each side of each hull.

I found that if you're going to set your nail heads it's best to do it while the glue is still pliable. Some glue is bound to get on the rings of the nails as you drive them in. If you wait until the glue has set then you break whatever hold it has on the nail. This reduces the holding power of the nail a great deal, even if it does look pretty on the outside.

On the keel laminations of a Wharram cat you have to use screws. The plans don't tell you this and I didn't. The result was that I had a gap big enough to shove your hand through. This was the main reason I had to lay the hulls on their sides. I poured epoxy putty along the keel to plug up all the openings. It added great strength but I could have taken a young lady dining and dancing two nights running for what it cost me.

As mentioned earlier I'm not very bright and big mistake number one was quickly followed by big mistake number two. Where the plywood skin comes together at the bow and stern there is a gap to the stringers. It must be bolted to the stringer in order to pull it in. The plans don't mention this either and I ended up with another gap of about an inch. I fiberglassed along the bottom of it and poured in more epoxy putty. And another young lady lost out. Although these set-backs are great fun they make you wonder about the sanity of what you're doing.

Although by nature I am not a joiner or groupie I do belong to the Northwest Multihull Association. I thought I might be able to buy equipment through the club cheaper than other ways. But their idea of cheap and my idea of cheap are not the same. If you work for a living the outfit you work for is in the business of buying and selling something. I stumbled into a job with an aircraft surplus house which had a hydraulic department. They supplied local fishermen with hydraulic equipment for their gear. And better yet they sold to the places which in turn sold to fishermen. Otherwise, it is a dumb job.

Fishing equipment has to be seaworthy and strong. The living of fishermen depend on it. When you're in a business even remotely connected with commercial fishing all kinds of doors open up for you. They sure opened up for me. When buying hardware for your boat I am convinced you should stay away from yachtie places. Go to work boat places. Also I bought all my metal as raw stock and made boat stuff myself. Out of one piece of oak I am making all my cleats. I'm also making all my own blocks.

But then *KAUAMEA* is not a racing boat. I crewed on racing boats, which is why I'm building a cruising boat. With a Chinese Junk ketch rig. Skippers on racing boats do not have a full string of beads.

Because Polynesian Catamarans have a narrow beam to length ratio they do not offer lots of living space inside. In fact they probably offer less living per foot than any other kind of vessel. Nevertheless, it is these narrow hulls which make the polycat so seaworthy. For me that is more important than living space.

by the hand and lead him along a course in boatbuilding. For two years after purchasing the plans I walked around with the plans in my left hand and a boat building book in my right hand. I would suggest anyone contemplating building a Wharram cat go to his local library and in the card index look up the words *Boat* and *Boatbuilding*, and read every book listed there. But it isn't enough for me to *read* a book; I have to *own* it. As a result, I have hundreds of dollars worth of books covering everything from fasteners to navigation. And I don't know how I'm going to fit them into *KAUAMEA* once she's launched.

Those who have built houses, bridges, or cities will have no trouble with the Wharram plans. But if you're like me and have never built anything worth a damn in your life you are going to need help. I'm not very bright but I do read a lot, and this has really helped me. But I realize there are those who don't read, who don't like to read, who hate reading. For them the only answer is the spoken opinion. Most opinions are worth about what you pay for them. I would not value the building opinions of someone who has not personally built a boat. The fact that he knows somebody who knows somebody would be meaningless. But I would hang onto every word of somebody who had built *to completion* any kind of boat. And I would buy dinner and a night of drinks for anyone who has completed the building of a multihull.

But the Wharram plans show that a Polynesian Catamaran is easier to build than most other boats. I built a balsa model first using one inch to the foot dimensions and making it lumpy with mistakes. This took me eight months and I was amazed that the thing ended up looking like a boat. And not a bad looking boat either. There is no way I can describe how the completion of this model encouraged me to move on to the big boat project. I might add that at no point have I regretted those eight months, nor have I ever considered them a waste of time.

One place some builders feel is a good source of information is the designer or the outfit peddling his plans. Not so. Some of these outfits even go so far as to advertise they are always available for any problem the builder might have. Not so. I feel the majority of multihull designers today are spending too much time around the slide and movie projector and not enough time *out there*. There are exceptions, of course. Jim Brown is one. Jim Wharram is another. These men not only designed boats but built one and moved aboard for extended voyages. I value their opinions because they come from personal experience. There aren't many other designers who have built their own designs then moved aboard.

Almost went with a Jim Brown trimaran. But if my income level in the past is any indication of what it will be in the future, I won't be building or owning a Searunner in *this* lifetime.. But Brown's Searunner construction manual is a wealth of rip-off ideas for anyone building any kind of multihull.

Polynesian Catamarans are cheap and seaworthy. Mine could have been built much cheaper than it was. I used (and am using) clear vertical grain fir, marine plywood, bronze ring nails, and all glue and resin is epoxy. This is not cheap. But my boat carpentry approaches wood butchery so I need the total holding power of epoxy. I'm using Chem Tech epoxy and find it as agreeable to work with as any of that stuff can get.

5. *GULFSTREAMER* - This 60 ft. trimaran was reportedly capsized in May, 1976, by two giant, rogue waves in succession.
6. *NOMAD* - 30 ft. trimaran capsized in Pacific. Crew lived aboard 7 days before rescue. Date unknown.

My own feeling on this as an owner of both keel boats and presently a 32 ft. trimaran is that I am not really very surprised. The AYRS has always made it abundantly clear that multihulled craft could capsize under extreme conditions, or if the wrong judgements are made at the wrong times. At least three of the above were very high performance racing craft. One can argue forever about degrees of safety in various yachts, but I note that the current favorites of the American buyers are very expensive keel and keel/centerboard yachts, most of which are completely unsuitable for offshore use although advertised for such.

Coincidentally, the 61 foot keel yacht *SORCERY* did a 360 degree roll in a Pacific storm on May 8, 1976. According to one news account, she lost all topside gear, spars and rigging and injured eight of her crew out of eleven - three of them seriously. Most keel yachts I see would sink immediately in such conditions.

There was considerable discussion on multihull capsize at our sailing meeting in Fort Myers Beach. The problem seems to get talked about in the following areas:

1. Capsize prevention. Is this possible? Sheet Release Gears? Inflatable Bags? Hydrofoils? Design? Seamanship? Water ballast or pumping?
2. Wave vs. wind capsize - influence of sea state.
3. Survival in inverted condition.
4. Design and build in advance to sail boat in inverted position under jury rig.

All four of these categories have been written about for years in the AYRS publications. Can anyone suggest a new approach to the problem?

SAILING MEETING NO. 4 - FLORIDA.

In late September, 1976, we will meet at Pensacola, Florida, to hold another $50 Regatta - hopefully with better masts and rudders. The Bowers brothers will be tough competition, and we hope some of the Texas boats might wish to challenge the winner of this regatta. For details and entry blanks write: Leland Hardy; 4426 Leola Lane; Orlando, FL 32806; or: Robert K. Bowers; 214 Payne Road; Pensacola, FL 32507; Telephone (904) 455-0205.

SAILING MEETING NO. 5 - TEXAS.

SM-5 will be held on October 2 and 3 on the campus of the Moody College of Texas A&M University on Pelican Island, Galveston. If you need information or help write or call: Ed Doran; 1114 Langford; College Station, Texas 77840; Office phone (713) 845-7141; Home phone (713) 693-5788; or: Jim McCloy; 3627 Q; Galveston, Texas 77550; Office phone (713) 744-7161; Home phone (713) 763-4987.

YACHT RESEARCH, SCIENCE & TECHNOLOGY

A LIFT STUDY OF SOME SAILING HULLS.

by John Herndon Thomson; UNIPOLYCON, INC.: 35 Congress Street; Salem, Mass. 01970. USA.

One of the numbers needed for the design of sailing vessels is the lift coefficient (or more properly, the slope of the lift curve), of the hull with its appendages, keel and rudder. (See Ref. 3, Chapt. 1 for a review of classical aerodynamics as developed for aircraft.) If this number is known, the lateral force that is available to counteract the wind force can be computed. If it is not known, a proper engineering design is not possible.

Currently available books on sailing yacht design do not show how to determine or use this coefficient, and as a consequence, many of the design choices relating to keel design and sail plan are made more from historical precedent than technical necessity.

There has been considerable speculation in the pages of the AYRS on the ability of various shapes of hulls and keels to perform as lifting surfaces for windward sailing. There is general agreement that experimental data from aircraft wing tests are directly applicable for fins or foils which are relatively deep and narrow, provided they are not ventilated and are not too near a free surface. However, the composite foil made up of a hull, keel and rudder makes a very low aspect ratio system that falls outside normal aircraft experience. This is also true of traditional hulls such as clipper ships, fishing schooners, and various other work-boat shapes that have attracted attention.

Historically, a number of experiments have been performed to determine the lift characteristics of low aspect ratio foils. Yacht hulls generally fit the requirements of these experiments for the prediction of lift characteristics with one major difference. The presence of the free surface of the water alters the situation theoretically. It is clear that a difference in pressure on the sides of a keel operating near a free surface will result in different water levels on either side of the hull. Also, the waves generated by the motion of the hull will alter to some extent the pressure distributions on the sides of the keel. So, a complex situation exists that has not been adequately analyzed.

The investigation described in this article is an attempt to gather reference material on the subject of lift of low aspect ratio systems, and correlate the predictions with a series of tests using the laminar test facility described in Appendix I.

On the whole, the test data confirmed the predictions quite well, and the curves presented provide a means of estimating the effective lift curve slope for many combinations of hulls and appendages. This information probably will be of interest to many AYRS members who are concerned with the lift characteristics of sailing boats generally. We found it specially

This ratio of boat speed to apparent wind speed is of interest. Often of even greater interest is the ratio of boat speed to true wind speed:

$$\frac{V_B}{V_T} = \frac{\sin\gamma}{\sin\beta}\frac{V_B}{V_A} = \frac{\sin\gamma}{\sin\beta} K\sqrt{\sin\delta_H}$$

γ (gamma) is the angle between the boat's course and the true wind.

Now recall the Course Theorem

$$\beta = \delta_S + \delta_H .$$

Thus now δ_S enters the formulation. With k and the two drag angles, δ_S and δ_H, all known, the performance can be deduced from these equations.

At times, it is valuable to know the best speed made good directly to windward, derived from the preceding equations:

$$\frac{V_{MG}}{V_T} = \frac{\sin\gamma\cos\gamma}{\sin\beta} K\sqrt{\sin\delta_H} .$$

In this way, k, δ_S, and δ_H define the performance of a sailboat -- another means of pointing out the importance and usefulness of the drag angles.

(For those who have been accustomed to thinking in terms of lift/drag ratios it may be worth repeating the direct relationship between those ratios and the drag angles: lift over drag is the cotangent of the drag angle.)

These parameters are not, of course, the same for different sailing angles and different sailing conditions for a given boat. In any one calculation, the values of the three which apply in the particular situation under study must be used. "Particular situation" means the combination of wind strength, sailing angle, choice of sails, trim of sails and hull, sea conditions, etc.

As has been pointed out, not nearly enough is known at present of actual values of the drag angles to enable many reliable calculations with these equations. When gradually the data do become available, more precise results can be expected.

But we need not simply wait for the data. Much can be done now. For example, a possible point of performance (k, δ_S, δ_H) can be assumed. Variations from this can be figured as one of the parameters is altered systematically. Thus the effects of postulated changes in a sailing craft can be estimated.

MATERIALS AND BOATBUILDING

BUILDING A WHARRAM CATAMARAN: KAUAMEA

Letter from George Snyder; P. O. Box 66538; Seattle, WA 98166.

Haven't received the U.S. bi-monthly yet so am holding off on opinions. On what members are interested in, out of the three thirds, I'm involved in two - building and cruising.

The following is a mixture of opinions, ideas, and experiences I've picked up and am passing along regarding the building of a Wharram cat.

First off, the Wharram plans are not going to take the wide-eyed builder

5. AYRS AIRS 2; 1972.
6. AYRS AIRS 4; 1972.
7. AYRS AIRS 5; 1973.
8. AYRS AIRS 7; 1973.
9. AYRS AIRS 8; 1974.
10. AYRS 83A; January, 1976: "Primer of Yacht Research."

DRAG ANGLES, Part IV -- THE ANALYSIS OF SAILING PERFORMANCE.

By Henry A. Morss, Jr.

The earlier parts of this series have given a qualitative view of the two drag angles of a sailing craft and of their importance. Here, for the reader who is ready to follow some elementary mathematics, is a more quantitative approach to the analysis of sailing performance which shows the key role that the drag angles can play.

The background for this was laid in AYRS 82, "Design for Fast Sailing," Chapter IV, with applications in Chapters IX, XXX, and XXXII. It was further extended in the present author's paper "Forces and Angles in Sailboat Performance" presented on Jan. 24, 1976, before the SNAME New England Sailing Yacht Symposium, held at the Coast Guard Academy in New London, Conn.

In that scheme, total sail and hull forces are expressed:

$$F_S = 0.5\,\rho_A\,C_S\,A_S\,V_A^2$$

$$F_H = 0.01\,K_H\,W^{2/3}\,V_B^2.$$

For a boat sailing without acceleration, these two forces must be equal, and opposite and in the same line. When they are set equal, we find

$$\frac{V_B}{V_A} = 0.585\,\frac{\sqrt{A_S}}{\sqrt[3]{W}}\sqrt{\frac{C_S}{K_H}}\,.$$

Here C_S and K_H are coefficients of total forces of "sail" (including all parasitic windage) and "hull" (entire underbody); sail area, A_S, in sq. ft.; boat weight, W, including crew, all supplies, gear, etc. on board while sailing, in pounds. The speeds are usually in knots.

Now, the substitution

$$K_H = K_{HF}/\sin\delta_H$$

is introduced, where K_H is the coefficient for the total hull force and K_{HF} is the coefficient for the fore-and-aft component of that force (the drag component) along the direction of motion. Notice that the hull drag angle enters the picture at this point. The value of the substitution lies in the fact that at fixed or only slightly varying boat speed K_{HF} does not vary much as δ_H ranges over its entire span, whereas K_H varies greatly.

From these we get

$$\frac{V_B}{V_A} = K\sqrt{\sin\delta_H} \quad \text{WITH } K = 0.585\,\frac{\sqrt{A_S}}{\sqrt[3]{W}}\sqrt{\frac{C_S}{K_{HF}}}.$$

interesting for the light it shed on the performance potential of clipper ships and other traditional hull shapes.

Limitations on the data presented should be noted:

1. The test data were all taken with the hull essentially upright, that is, heel angle near zero.
2. Rudder angle was zero for all the tests. This condition, with the helm amidships, is the normal minimum drag condition.
3. All the tests were run at Froude Number of .20. This corresponds to a speed-length ratio of about .65. This speed was chosen to avoid major complications with wave formations, and to approximate the average speeds of many of the larger sailing vessels.
4. No data is shown that is directly applicable to multihulls or twin keel (bilge keel), arrangements. These areas of investigation would be very interesting and a valuable addition to our knowledge.

All of us, by now, are familiar with the basic lift equation:

$$F_L = C_L A \rho V^2/2g \qquad (1)$$

Any set of consistent units can be used, for example: F_L = lift force in lb.; A = lateral area of hull, keel, and rudder in sq ft; ρ = density of water in lb/cuft; V = velocity in ft/sec; and g = acceleration of gravity, 32.2 ft/sec^2.

A quick dimensional check will show that C_L is a dimensionless coefficient. This equation really defines C_L since the other quantities are either measured or known.

The effectiveness of a lifting surface is related to the aspect ratio of the surface. This ratio is defined for a hull and keel as:

$$AR = 2d^2/A \qquad (2)$$

where d is the maximum draft in ft; and A = lateral area of hull, keel, and rudder in sq. ft.

The concept of aspect ratio was originally worked out for airplanes which are symmetrical, with a wing on each side. The factor of 2 in the equation above lets us relate a boat hull with a keel to general aeronautical data and theory.

The lift coefficient C_L varies with angle of attack α and aspect ratio approximately as shown in the diagram below for airplane wings.

It is evident, almost instinctive, that C_L is very nearly a straight line function of α for a particular value of aspect ratio for at least 6° or 8° of α.

There is a deceptively simple equation that relates these variables:

$$\alpha = \alpha_0 + \frac{C_L}{\pi(AR)} \qquad (3)$$

α_0 is the angle of attack resulting from an aspect ratio less than infinite, in Radians. AR and C_L as previously defined.

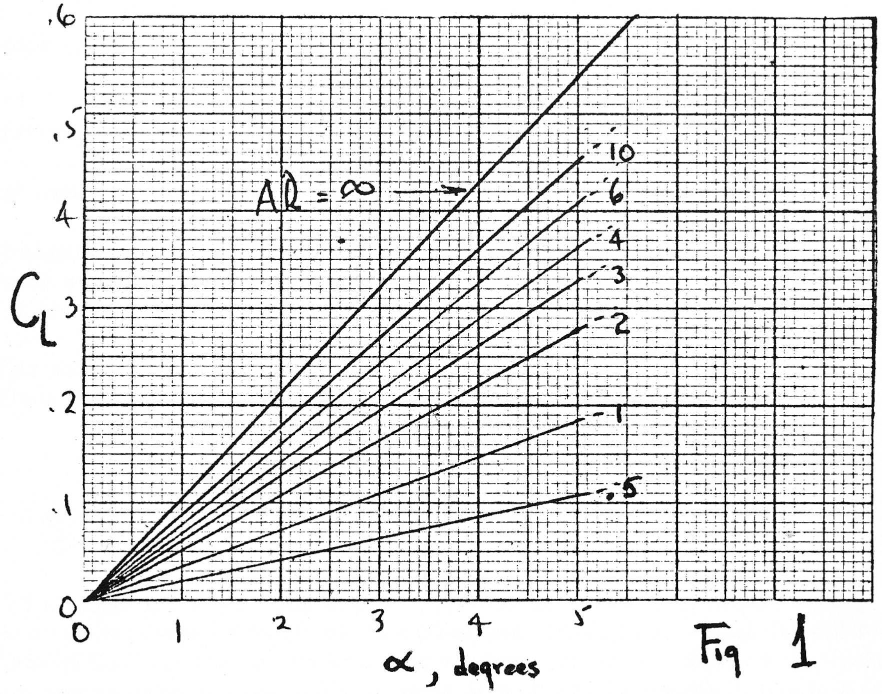


Fig 1

α_o for $C_L = 1$ is about 9.3^o for thin foils. Fig. 2 shows a representative curve from Ref. (3). The section lift coefficient (C_L), plotted against angle of attack (α_o), indicates what to expect from a thin wing corrected for infinite aspect ratio. If this is substituted in equation 3, α can be computed for a range of aspect ratios at CL = 1. From this the ratio of C puted

puted for a range of aspect ratios at $C_L = 1$. From this the ratio of C_L/α can be calculated. This is simply the slopes of the curves in Fig. 1. These can be plotted against aspect ratio, where they form the top line in Fig. 3, labeled: $\alpha = \alpha_o + C_L/\pi(AR)$

For use with boats, the angle of attack symbol α is generally changed to λ, indicating leeway angle. So the curves show C_L/λ plotted against aspect ratio.

Equation 3 is not really valid for aspect ratios much below 1.0. As a practical matter, it is quite close to other values we have found down to around .25.

Several references on the subject of low aspect ratio foils and wing-body combinations (Ref. 1, 2, 4), agree generally on the form of the equation:

$$C_L = f_1\alpha - f_2\alpha^2$$

which turns out to be a purely empirical fit of the data.

A useable version of this equation, as found in Hoerner (4, p. 7-16, 17) is:

$$C_L = .5\pi(AR)\sin\alpha + k\sin^2\alpha\cos\alpha.$$

less subject to ventilation. If the hydrofoil configuration is laterally asymmetric *(proa)* for which there are strong arguments *(see paper III),* then the foil section must be the same from either direction and the likely choice is the ogival section *(flat on the bottom and a constant radius on the top).*

The maximum possible L/D for an ogival section is only slightly less than is possible with a blunt-nosed section as Fig. 4 shows, but in practice the advantage of a blunt-nosed section can only be realized with a deeply submerged foil and then only if the section and particularly the leading edge can be made and finished to a standard usually unattainable by the amateur constructor.

There is a particularly handy technique for constructing ogival-section foils that was first brought to my attention by Dave Keiper. In order to machine the foils a wooden cylinder with an equilateral polygon cross section and a carefully centered metal shaft is constructed as shown in Fig. 5. Bar stock is then mounted on each flat and the lot is then chucked into a lathe and machined to a constant radius. The choice of the number of sides determines the ratio t/c. In order to make a Go 708 *(Gottingen)* section (an early German glider section) as seems advisable since data is available, an eleven-sided cylinder should be used. For this section the radius/chord ratio is 1.7.

Aluminum or laminated wood can be used for foil construction, but a much better strength/weight ratio can be achieved by using a PVC foam core (e.g., heavy-grade Airex) machined somewhat undersized. This can then be laid up using epoxy and alternating layers of glass and Kevlar cloth and carbon fibers. A layer of microballoon putty is trowled on and the final machining is then done on the lathe. Thus eleven beautifully-finished ogival foil blades, each perhaps four feet long, are produced fairly easily.

Editor's Note:

This concludes the Series written by Joe Norwood on Hydrofoils for Sailing Craft, and it is hoped that this excellent presentation will stimulate experimenters to build and sail hydrofoil-equipped boats. It must be emphasized that there are two major applications of hydrofoils: one is to lift the hull out of the water to reduce resistance and hence increase speed; the other is to prevent heeling instead of using ballast or float hulls. Now that multihulls have become almost respectable and accepted on the scene of international yachting, it seems as though most of the unknowns on catamarans, trimarans and proas have been resolved, and we will henceforth see but minor improvements. Therefore, the yacht of the future may well be the foil-stabilized sailing vessel. Dave Keiper in his 14,000 miles of criusing a 31 ft. hydrofoil yacht is the pioneer who has shown us that such is possible. (AYRS 83B).

We repeat some of the major references on hydrofoils:

1. *Design for Fast Sailing* by Edmond Bruce & Harry Morss; AYRS 82; 1976.
2. *Sailing Hydrofoils*; AYRS 74; 1970.
3. *Hydrofoil Sailing;* Alexander, Grogono & Nigg; London; 1972.
4. AYRS AIRS 1; 1971.

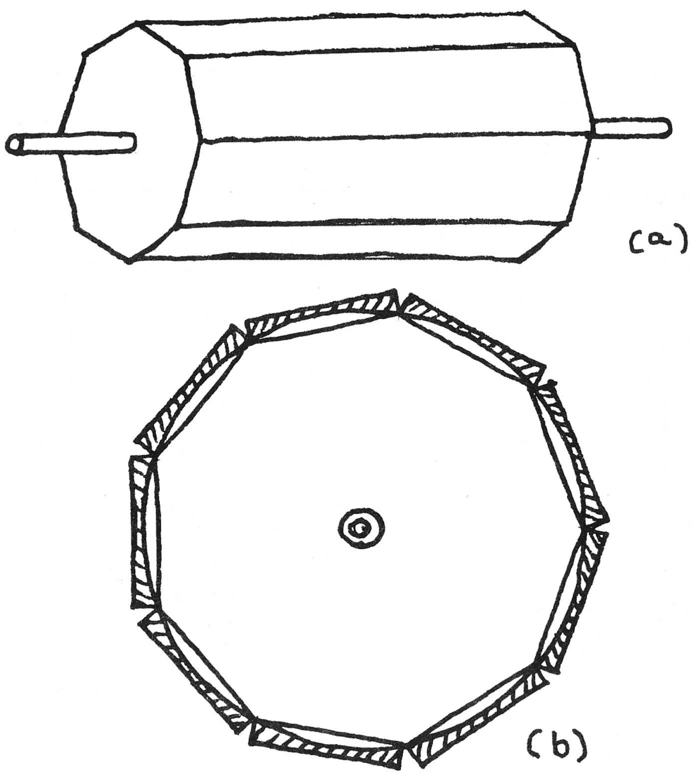


Fig. 5

data, C_{DO} may be estimated by using the empirical relation

$$C_{DO} \approx 0.004\,(1+1.2\,t/c) + 0.11\,(C_{LO} - C_L)^2, \qquad (14)$$

where t/c is the thickness/chord ratio. The strut drag is estimated in three parts. The body of the strut has a drag that can be estimated using the first term of Eq. (14). The junction with the foil gives rise to drag effects that depend critically on the fillet or fairing used. The best source of empirical data on this question is Hoerner, *(Hoerner, S.F.; FLUID-DYNAMIC DRAG - 1958)*. Lastly, a spray drag arises at the water surface; for sharp-nosed sections a coefficient of 0.02 can be taken based on chord times thickness as the reference area. This same term should be applied to determine the spray drag at the ends of surface-piercing foils.

As a reward to the reader who has managed to plow through the foregoing tedious but necessary material, I would like to pass along my views on amateur hydrofoil construction. The first question involves the selection of a suitable foil section. In reaching a decision the following factors should be considered. For surface-piercing foils, the most likely type for sailing application, the drag at the surface is minimized by using a section with a sharp leading edge. Such sections have a far more even pressure distribution *(see Fig. 6, part II, of this series in AYRS 83B)*, and consequently are

Using the value of k = 3, it is shown plotted in Fig. 3 and Fig. 4 below values of aspect ratio .23. It is important only for the fact that at these low aspect ratios, the available lift is substantially higher than that predicted by simple linear theory. The physical reason for this is that the stream of fluid deflected by the "wing" increases with the angle of attack.

The top line in Fig. 3 and Fig. 4 represents the maximum possible lift curve slope that can be obtained from a well shaped thin foil of a given aspect ratio. Any lower value of lift curve slope for a particular aspect ratio is caused by the deteriorating influence of the hull, which in general, has lift characteristics which are poorer than thin foils.

In any case, these are not very effective foils compared with those of higher aspect ratio. Those of us who have yearned after magical lift from low aspect ratio keels must simply swallow the pill. There is no Santa Claus.

THE MODEL TESTING PROGRAM.

The models that were investigated fell into two groups. It is possible, in the United States, to buy plastic injection moulded models of a number of historically significant vessels. These include the *Cutty Sark*, the yacht *America*, *USS Constitution*, the Gloucester fishing schooner *Gertrude L. Thibault* and others. Models we used were partially assembled, so they would float. Their gross measurements were checked to determine that they did conform reasonably well to their parent shapes. Models were chosen in the size range to assure laminar boundary layer flow. A suitable model of *Messenger*, a Skipjack from the Chesapeake area, was also available. (See Chappelle, Ref. 5, Page 323). The other group of tests were with a single, rather shoal hull, with a wide variety of added-on keels and rudders. The effect of this approach was to give us a series of test hulls with aspect ratios ranging from less than .15 to over 2.5 with a minimum of model building effort. (See Fig. 6, 7, 8).

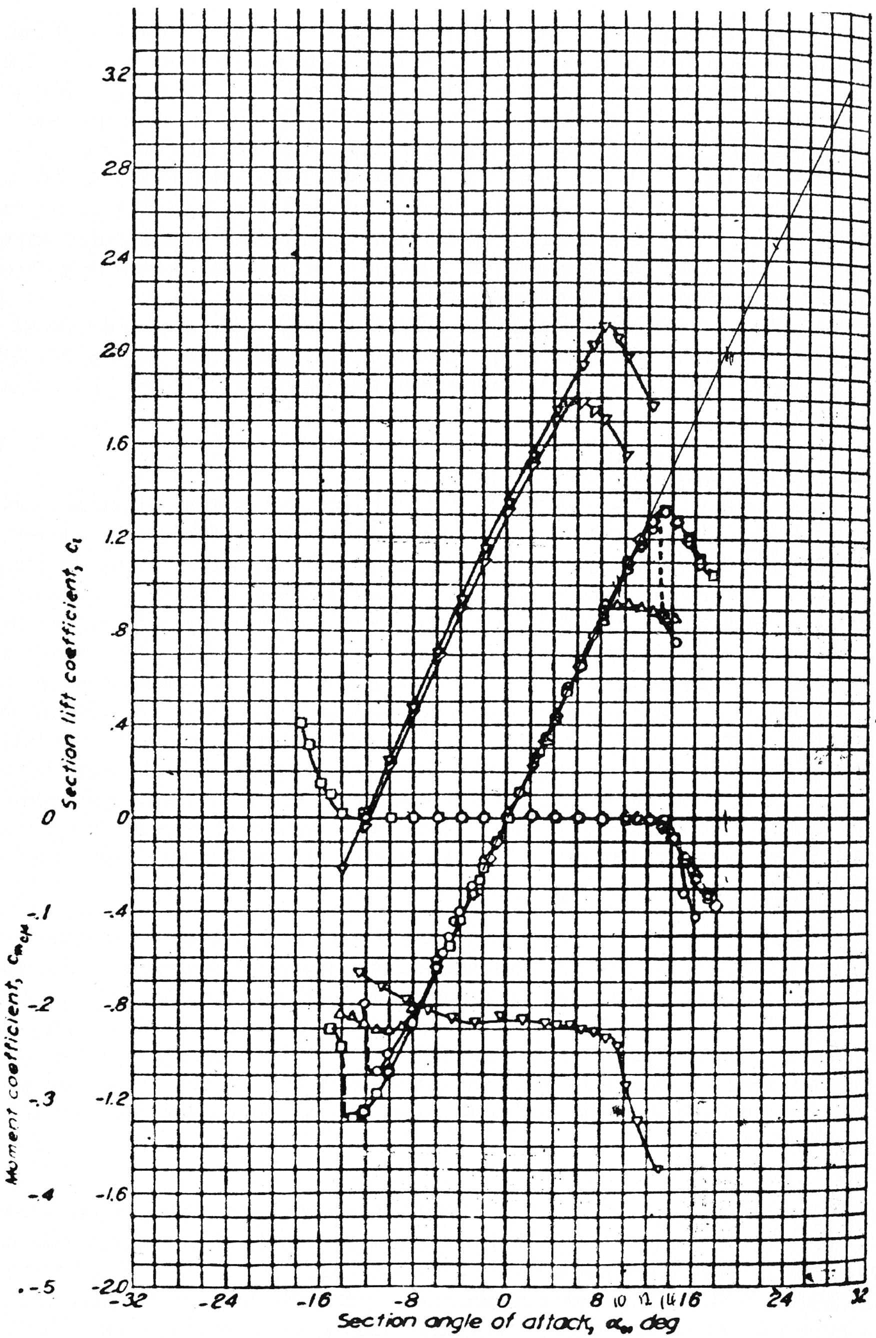
Appendix I describes a small towing tank and the instrumentation currently in use, so the testing methods will be obvious. In practice, a series of runs is made to determine drag angle for a series of leeway angles from 2^o through about 8^o of λ. Then another series of runs is made for drag for the same series of leeway angles. All runs for the series are at the same carriage speed. From this data, the lift can be computed. Then, with physical measurements of the hull available, the lift coefficient and its slope can be computed.

RESULTS.

Figure 3 shows the collected results of some of our more reliable tests.

The small outline sketches show the approximate shape of the hull and keel for the points indicated.

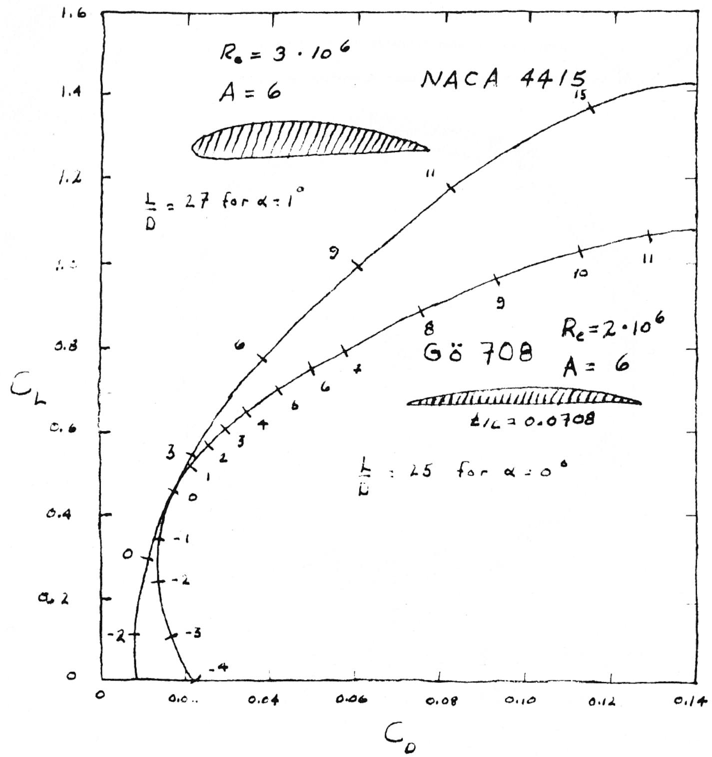
Cutty Sark is the lowest aspect ratio complete hull we tested, and results show her to be the least effective lifting surface of the lot. Her lift properties, in our tank, are very sensitive to trim. Trimmed by the stern, she is best. Trimmed by the head she is substantially poorer. The point shown is her best.



NACA 0009 Wing Section

FIG 2

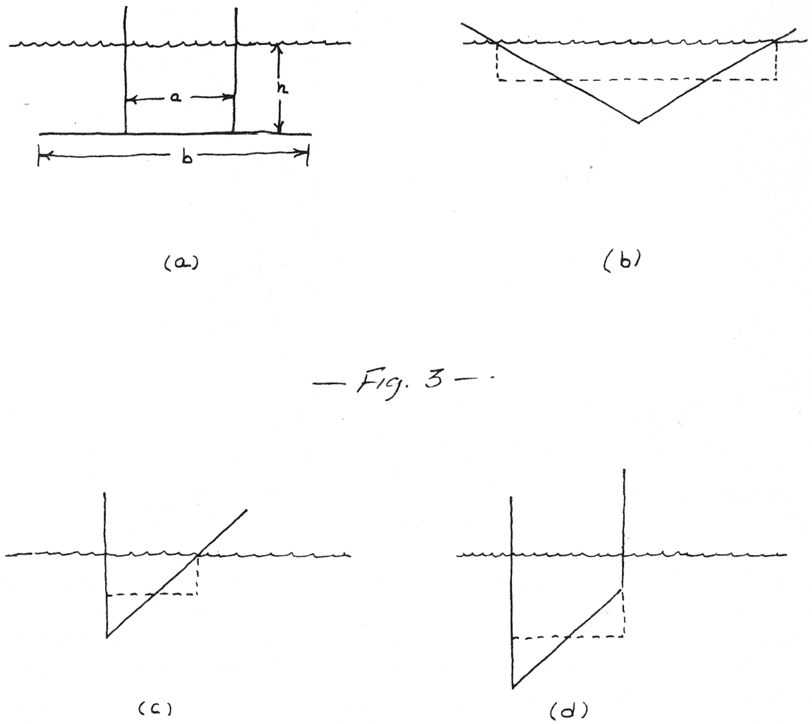
$\frac{\alpha}{C_L} = 9.35$



The drag coefficient for the lifting part of the hydrofoil system (excluding struts) is given by

$$C_D = C_{DO} + C_L^2\left(\Omega + \frac{1+\sigma}{\pi A}\right) \qquad (13)$$

where C_{DO} is the section drag coefficient. In the absence of experimental



— Fig. 3 —

Only for large Froude number, aspect ratio, and submergence depth does this equation reduce to the simple expression

$$C_L = C_{L0} \left(\frac{A}{A+2}\right) \qquad (12)$$

often used by amateur experimenters.

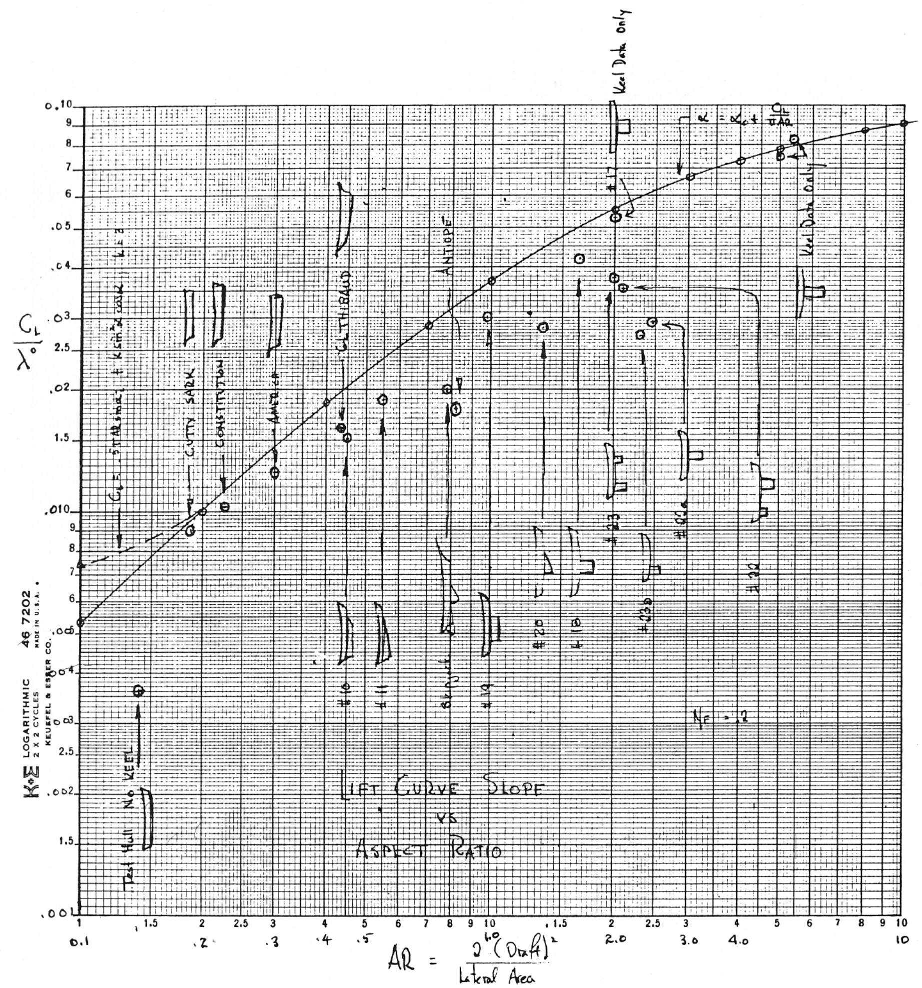


Fig. 3

Constitution is probably too plump aft to avoid separation, but she is included because the lift is likely not to be seriously affected. She is relatively deeper and has a drag to her keel (deeper aft than forward, both of which improve her lift properties.

America has more drag to her keel, and is relatively deeper also, and thus is better still.

Gertrude L. Thibault is a very nicely shaped fishing schooner with a long curved keel, no forefoot, quite deep aft, and very hollow garboards.

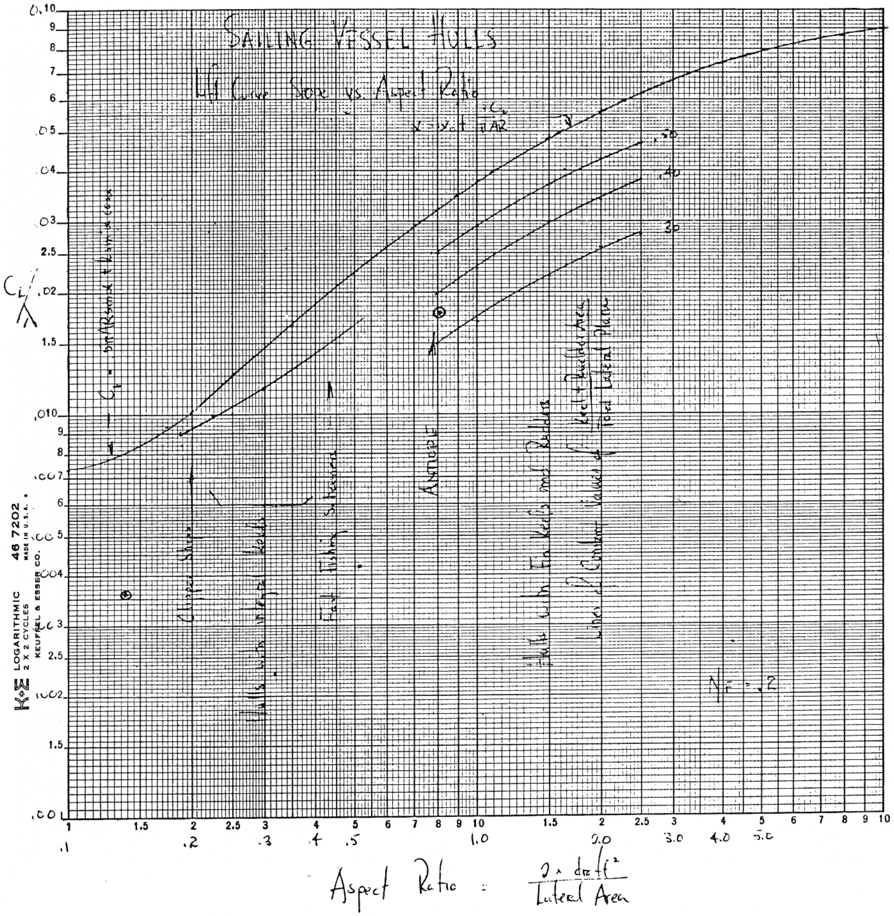


Fig. 4

Messenger, with her centerboard, has an aspect ratio of .78. Her centerboard, in the case of our model, is made of a thin aluminum sheet, and she has a shallow rudder behind a long skeg.

All of the numbered points were made with the same model hull with different keels and rudders glued on approximately as shown. (Fig. 8 through 11).

Points 10 and 11 were long, low aspect ratio keels. They were the same except that 11 was cut away to a straight line from the heel of the

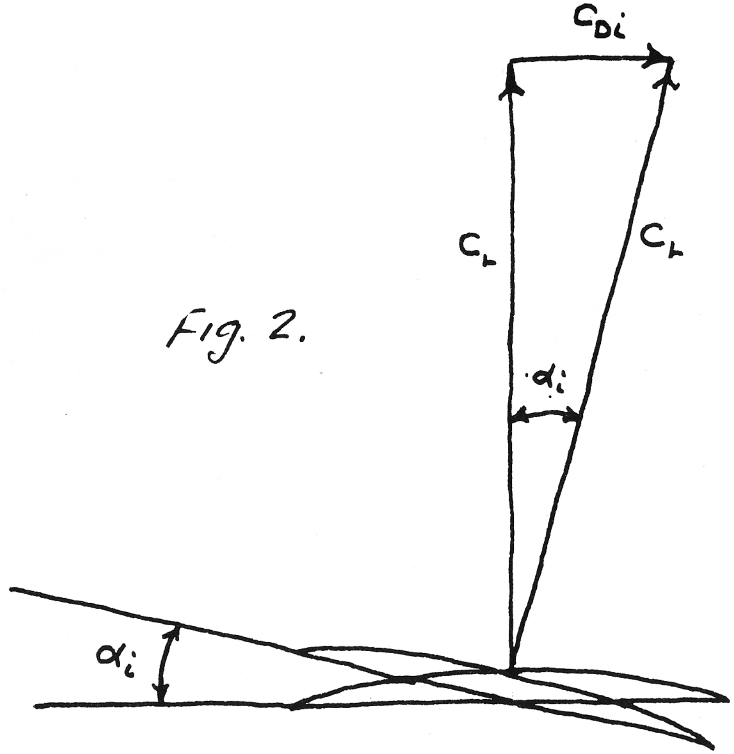


Fig. 2.

with aerofoils owing to the presence of struts and, in the case of surface-piercing foils, the air-water interface which inhibit spanwise flow. In Fig. 3a we show a horizontal hydrofoil of span b supported by two struts separated by a distance a. The effective aspect ratio for this configuration has been shown to we well approximated by

$$A = \frac{b}{c}\left[1 + \left(\frac{a}{b}\right)^3 \frac{h}{b}\right]. \qquad (9)$$

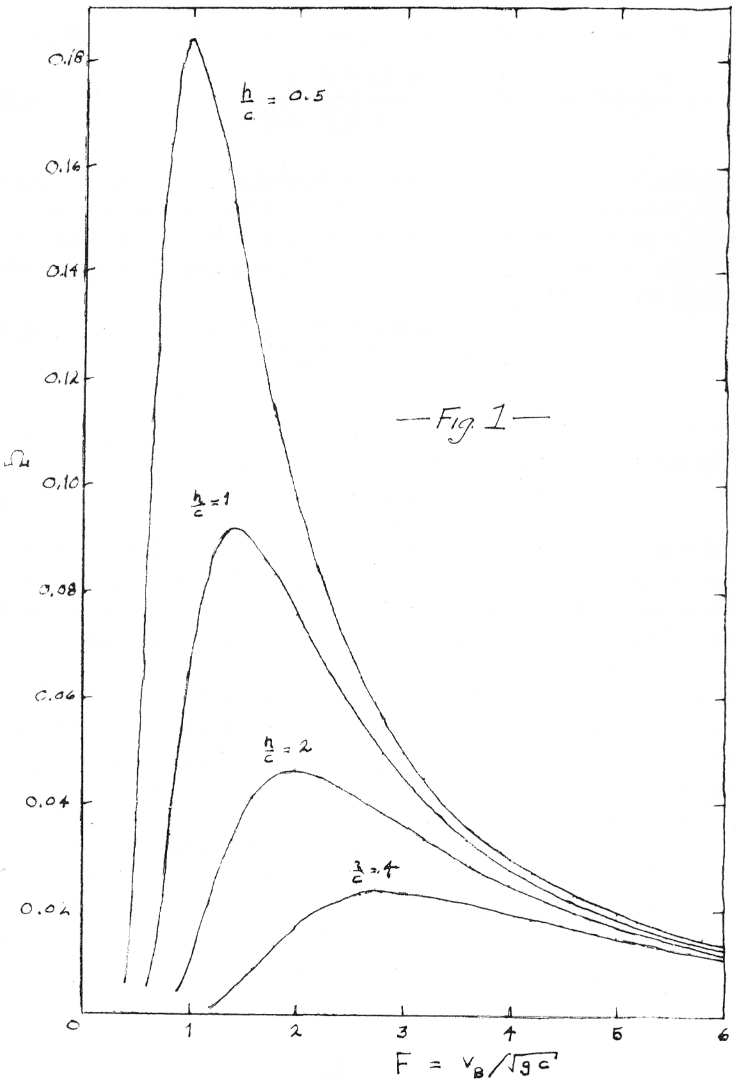
For a T-foil having a single strut $a \to 0$ and $A = b/c$ as expected. For a v-foil as shown in Fig. 3b, Eq. (9) can be applied to the equivalent configuration shown with dashed lines and one finds

$$A = \frac{b}{c}\left(1 + \frac{h}{b}\right) = \frac{h}{c}\left(1 + 4 \operatorname{ctn} \theta\right). \qquad (10)$$

The effective aspect ratios for the asymmetric dihedral foils shown in Fig. 3c and d are similarly evaluated.

Collecting the contributions from Eqs. (2), (3), (4), (6), and (8), the lift coefficient can be estimated as

$$\frac{\alpha_T}{C_L} = \frac{1 + 2/A^2}{2\pi K \cos\varphi \cos\theta} + \Omega + \frac{1+\sigma}{\pi A} \qquad (11)$$



The flow velocity that generates lift is perpendicular to the span. Thus if foils with a sweepback angle φ are used, then the two-dimensional lift slope must be multiplied by cos φ. This same sort of correction is necessary for dihedral. The angle of attack is defined in the vertical plane and is therefore decreased by a factor cos θ where θ is the dihedral angle.

The definition of aspect ratio for hydrofoils is a bit more involved than

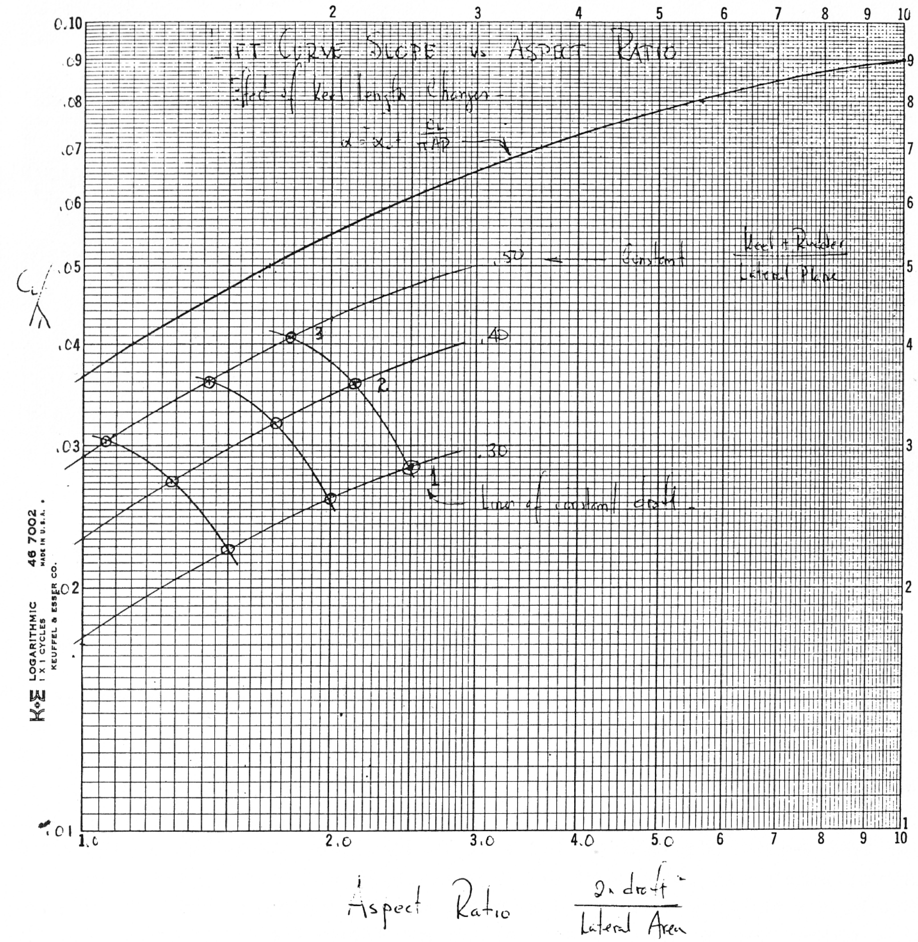


Fig 5

rudder to the forward point of the keel. So the draft of the two was the same but the area of 11 was reduced.

Figure 4 is a simple summary of many of our test results. The data shown as a line in the region of aspect ratios from .2 to .5 must, in real life, be a rather broad one to account for differences in detailed hull shapes. The best of the clippers, fishing schooners, and other fast vessels are probably near this line. Full vessels, or those with very shallow keels, could be substantially lower. The test hull point at aspect ratio of .14 and

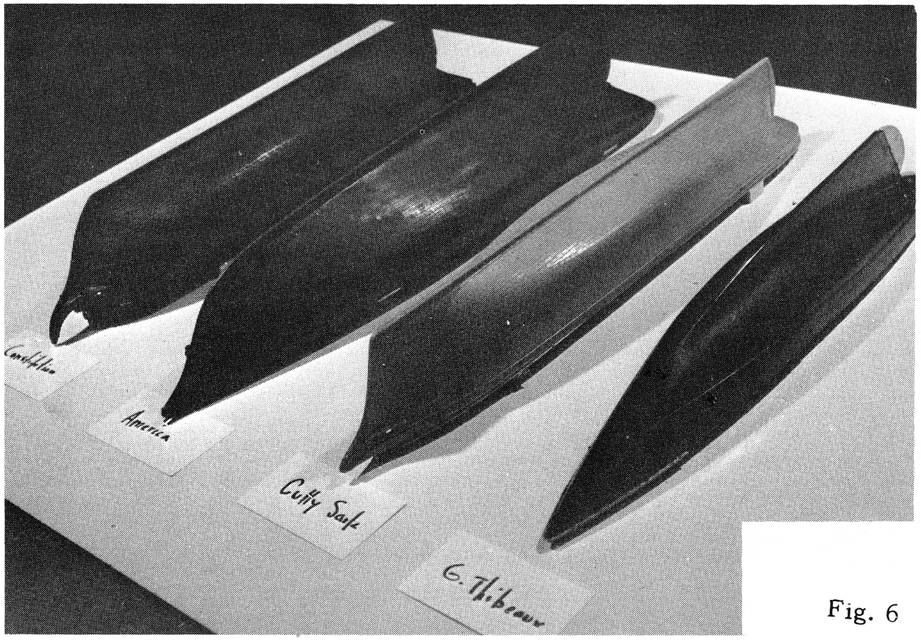


Fig. 6

C_L/λ of .0036 is probably near the bottom of the possible area for vessels with little or no lateral plane, and well faired hulls.

Data for the region from aspect ratios of .5 to .8 are so sparse as to as to hardly warrent a summarizing line.

It is evident from inspection of the data from aspect ratios of .8 to 2.5 that the size of the keel in relation to the hull is an important variable in the values of C_L/λ obtained. As a next step in the analysis, for each of the test points, the ratio of the area of the keel and rudder to the total lateral plane was calculated and a cross plot was made. The composite results are shown in Fig. 4. Lines of constant values of the ratio of keel plus rudder area to total lateral plane are shown for our test hull for .3, .4, and .5.

As a check on our procedure, a flat, round wooden dish was made as a test hull which would have no lift, and several keels were tested in a way that was analogous to wing tests in a wind tunnel. (See Fig. 12.) The results are shown at the top of Fig. 3, and indicated as "Keel Data Only." The points come close to the theoretically predicted values of C_L/λ.

We tested our test hull as a bare hull with no added lateral plane, and obtained the point at AR = .14 and $C_L/\lambda = .0036$. This, we presume, is representative of a nicely faired round bottom hull with no keel or rudder. It would be hard to imagine a less effective lifting surface.

An interesting and very important point is shown on both Fig. 3 and Fig. 4. It is the calculated data from J. S. Letcher's recent paper (Ref. 6), on the full scale tests of *Antiope*. It is the only reliable full scale data available at this time, and represents a unique connection with reality.

the drag induced on the lower wing of a biplane by the presence of the upper wing. It can be approximated by multiplying the ideal slope 2π by a

$$\text{FACTOR, } K = \frac{(4h/c)^2+1}{(4h/c)^2+2} \qquad (3)$$

where h is the submergence depth of the hydrofoil and c is its chord. The lift loss is only about five percent at $h/c = 1$ and increases to a limiting value of fifty percent at $h/c = 0$ at which point the foil becomes a planing surface having an ideal lift slope of π at infinite span. The wave effect can be accounted for by adding a term

$$\Omega = \frac{\exp(-h/cF^2)}{2F^2} \qquad (4)$$

where F is the Froude number defined on the basis of the chord

$$F = V_B/\sqrt{gc} \qquad (5)$$

and g is the acceleration of gravity, ($g = 32\ ft/sec^2$). This function is plotted in Fig. 1 for several values of h/c. It can be shown that the peaks of these curves occur at a boat speed of $v_B = \sqrt{2gh}$ which is well below takeoff speed. Thus hydrofoils pass the wave 'hump' with ease at low speed which is, of course, one of their chief advantages. It should be mentioned that this approximation breaks down when the craft is operated in shallow water. The maximum speed of a gravity wave in water of depth d is $v_w = \sqrt{gh}$. For boat speeds exceeding v_w the wave train cannot keep up and a more complex theory which we shall not go into here must be used.

As in aerofoil theory, a hydrofoil of finite span is subject to a further lift loss and induced drag as a result of the vortex system at the tip or tips. A wing, of aspect ratio A and elliptical spanwise loading has an induced lift angle and drag given by

$$\frac{\alpha_i}{C_L} = \frac{C_{Di}}{C_L^2} = \frac{1+\sigma}{\pi A}, \qquad (6)$$

where $\sigma = 0$ for aerofoils and

$$\sigma = \frac{A}{A+12h/c} \qquad (7)$$

for hydrofoils. The equivalence of induced drag and its associated induced lift angle is illustrated in Fig. 2. Physically, this loss is associated with diverging lateral waves arising from the trailing vortices. This correction applies only for high Froude numbers; two dimensional theory gives a reasonable estimate at low *(sub-foiling)* speeds.

For modest aspect ratios, deviation from elliptical planform can be taken into account by multiplying the ideal slope 2π by a correction factor

$$E = (1+2/A^2)^{-1} \qquad (8)$$

have to be equalised by screens as Edmond Bruce did with his wind tunnel.
3. Surface tension effect at the outflow into the test section might turbulate the water flow at the surface. I cannot think it would be of importance.
4. Outflow problems. I think the jet should be extremely stable. One can think of the Gulf Stream which flows, a few miles wide, right across the Atlantic. Therefore, I guess that the water, if properly aimed, will enter the outflow with no problems. Any boundary layer which might appear should be so tiny that it will go in nicely without affecting the static water much. Even if it does, it would only result in a slow circulation of that water.

SUMMARY.

A re-circulation test tank is proposed which would be cheaper and easier to operate than previously-designed tanks of this type. Water flow speed would not be of vital importance in measuring the hull drag angle and need never be measured. The evaluation of the hull's performance can well be made by measurement of the hull drag angle only.

THE APPLICATION OF HYDROFOILS TO SAILING CRAFT - Part IV.

by Joseph Norwood, Jr.; 1021 Valencia Ave.; Coral Gables, Fl 33134.

In the conclusion of this series on hydrofoils as applied to sailing craft I want to discuss the calculation of forces generated by the motion of a hydrofoil through water and to pass on a few helpful hints on construction.

As most of you know, it is convenient to decompose the force vector into components perpendicular to the line of flow *(lift)* and parallel to it *(drag)*. The lift force L is defined in terms of the mass density of the water ρ, the speed of the flow v_B, and the foil area S as

$$L = \tfrac{1}{2}\rho v_B^2 S C_L \qquad (1)$$

where C_L *is called the lift coefficient.* It is a matter of experience that C_L increases linearly with angle of attack α over its normal operating range, that is, up to the stall point. The slope of this curve can be shown to be 2π where α is measured in radians or $\pi^2/90 \approx 0.11$ where α is measured in degrees for a foil of infinite length acting in an unbounded medium. Thus

$$C_{L0} = 2\pi\alpha_T, \qquad (2)$$

where α_T is the angle of attack as measured from the attitude of zero lift. This ideal lift coefficient slope is reduced by various factors.

A number of these factors, unlike those that affect the wings of an aeroplane, arise from the proximity of the water-air interface. In an unbounded fluid, the low pressure established on the more highly curved upper surface of the foil not only lifts the foil but also distorts the free surface above it such as to reduce the pressure gradient and consequently to decrease the lift. The free surface perturbation manifests itself as a transverse wave. The magnitude of these effects can be taken into account by including two additive terms. The lift loss due to pressure relief is similar in nature to

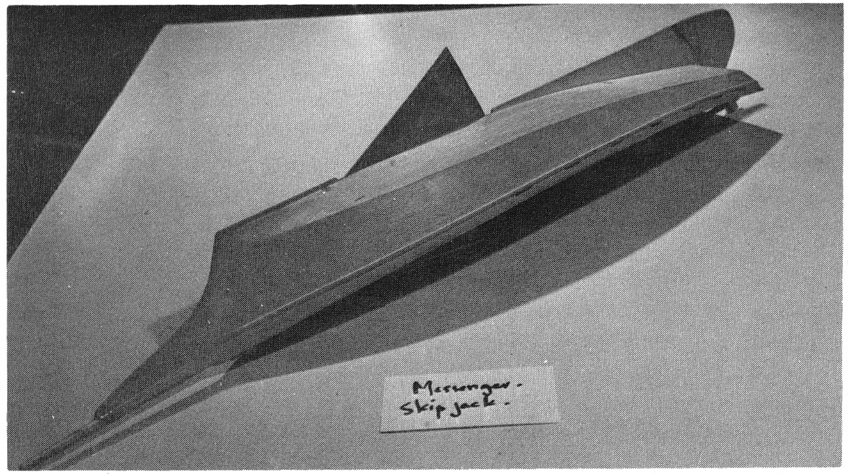


Fig. 7

There is a minor discrepancy which should be noted. The computed value of the ratio of keel plus rudder area to total lateral plane is .42, whereas the location of this point on our cross plot appears near .37. Some of the possible reasons for this discrepancy should be mentioned. *Antiope* was very well faired and rounded at the keel bottom. This tends to provide slightly less lift than the generally sharp foil tips that we used. The error is not very much, and may be consistent with the accuracy of our methods. In any case, this discrepency should serve as a warning that these curves should be used with caution. Limited data went into them, so confidence should be similarly limited.

USE OF THE DATA.

The basic question to be answered is: Is the lateral plane adequate in area to provide the needed lateral force at the expected speeds, to allow the boat to sail to windward at a reasonable leeway angle?

If the keel is too small, λ will be too large, and the drag will be high due to induced drag and perhaps separation losses.

If the keel is too large, λ will be small, and the drag will be high due to friction losses.

The steady-state analysis is relatively easy. At the design point, the lift must approximately equal the lateral force from the sails, or using Henry Morss' notations from Ref. 7:

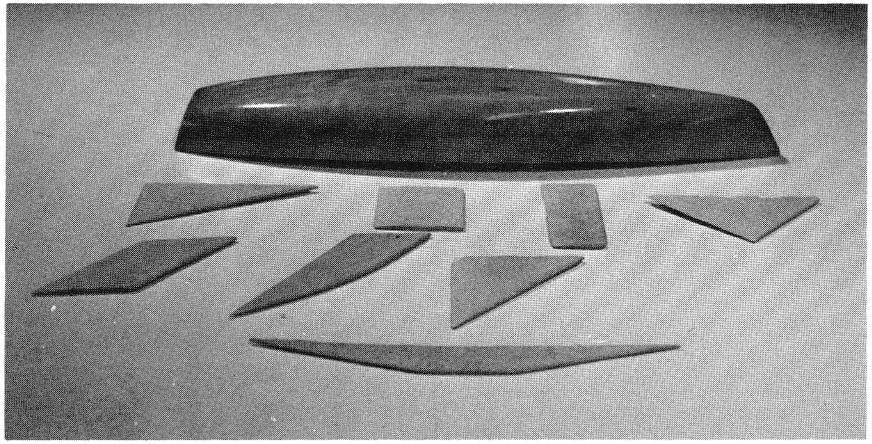


Fig. 8

$$L_B = F_S \cos \delta_H \cong F_S \; ; \quad (\cos \delta \cong 1)$$

AND $$L_B = A_B \left(\frac{C_L}{\lambda}\right) \lambda \frac{\rho_W V_B^2}{2g}$$

AND $$F_S = C_S A_S \frac{\rho_A V_A^2}{2g}$$

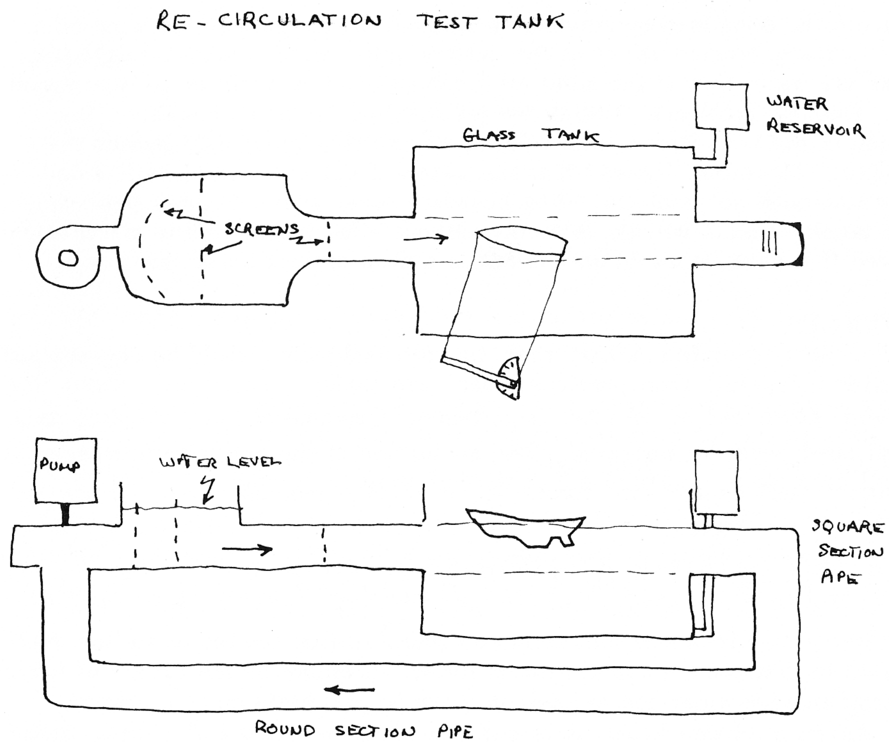
THUS $$\left(\frac{C_L}{\lambda}\right) \lambda A_B \frac{\rho_W V_B^2}{2g} = C_S A_S \frac{\rho_A V_A^2}{2g}$$

AND $$\lambda = \left(\frac{C_S}{\left(\frac{C_L}{\lambda}\right)}\right)\left(\frac{A_S}{A_B}\right)\left(\frac{\rho_A}{\rho_W}\right)\left(\frac{V_A}{V_B}\right)^2$$

which should be about 4^{o} if the keel area is about right.

In the above, L_B is the lateral force on boat in lbs.; F_S is the total sail force in lbs.; δ_H is the hull drag angle in degrees; V_B is boat speed in ft/sec.; V_A is the apparent wind speed in ft/sec.; A_B is the lateral area of hull, keel, rudder (underwater), sq ft.; A_S is the sail area in sq ft.; and C_S is the sale force coefficient, - 1.3.

V_A and V_B should come from preliminary design considerations. C_L/λ can come from Figure 4.



This second chamber is rectangular for a few inches. Then, the side walls curve in a quarter circle to make an exit passage of square section which discharges into the test tank. Another screen may be needed in this square section.

The test tank is a glass-walled tank of 100 times the cross-sectional area of the expected model yachts. The square-sectioned water jet flows across it from end to end, and it is hoped will still be exactly-shaped to disappear into a square-holed pipe which returns it to the centrifugal pump. Square pipes can be easily made into circular ones by appropriate conical fairings at the corners.

EVALUATION.

I think that this tank should work. The surface might not have the small water gradient of Mehaffey's tank because the water would be flowing across the tank by its momentum and would be supported by the static water. Possible faults are:

1. Vibration from the pump being transmitted into the test section. This could turbulate the flow around the model. At the worst, this should be no greater than with the Mehaffey tank.
2. Velocity gradients could occur across the test section. These would

A RE-CIRCULATION TEST TANK DESIGN.

by John Morwood; Woodacres; Hythe, Kent, England.

Test tanks are vital for the study of yacht design. Many exist but their workers shroud the results in secrecy, even though they often have been built with public monies. One can only suppose that the results do not mean as much as their users say. Indeed, with fully-restrained models on the close-hauled courses and from the few published results, I believe this to be so. The other explanation that the tanks only work for commercial gain is too incredible to be taken seriously.

Edmond Bruce clearly shows that, by the use of a suitable method, the figures for close-hauled performance of a yacht can be obtained. However, his method and tank are space-taking and a bit mind-boggling to the amateur researcher.

I would like to suggest that a simple figure of the: 'Hull Drag Angle,' is as good an index as we will ever need of the all-round performance of a sailing yacht. This drag angle includes the hull resistance to forward motion as well as the side force produced. The aeronautical equivalent of the 'Lift to Drag Ratio' of an aeroplane wing is the vital figure in that discipline, and I see no reason why we need any other. Naturally, it has to be interpreted with care and its limitations realised.

This article proposes a tentative design for a Re-circulation Test Tank which, with only a simple protractor for measuring the angle we are interested in, can be of immense value to yachtsmen and yacht designers. The water speed does not matter as long as it is below 0.6 or 0.7 of $V/\sqrt{L}$.

I will start by describing the design and point out the possible points where it could be defective later. Re-circulation test tanks are not new. I have seen one at Southampton University, and Bill Mehaffey built one himself in Michigan which correlated well with the results of Edmond Bruce's tank. *(See AYRS 32,16 and 56,70 for descriptions of the Mehaffey tank.)* The chief difference between the results of Mehaffey and Bruce was probably due to the slight water gradient in the Re-circulation tank.

The re-circulation test tank to be described here derives from the tanks of Edmond Bruce and Bill Mehaffey in that the models are small enough to be kept in a state of laminar flow which means that they are only about one foot long on the waterline. However, the main difference from other re-circulation tanks is derived from the Bruce yacht wind tunnel. Edmond found that a sail model placed in a smooth jet of air in a room needed only a large enough jet to cover the sail. The boundary of the jet stream was elastic, so there was no 'wall effect.' My suggestion is to place a hull scale model in a jet of water in a large, glass-walled tank. If it works, the amount of water which must be re-circulated is enormously reduced.

DESCRIPTION OF THE TANK.

A centrifugal water pump blows water into a chamber of 'D' shape with an open top. Curved, copper, wire-mesh screens distribute the flow so that it is nearly equalised by the time it reaches the flat side of the D. At this point, the water flow enters a closed chamber through another wire-mesh screen.

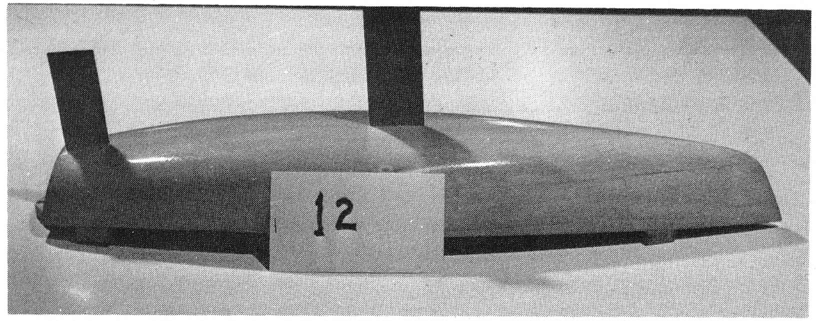


Fig. 9

Note that an error of 25% will result in a change of λ of only 1^{o}, so great precision does not seem necessary.

The transient conditions present additional problems. When a boat is starting from a standstill, as from a mooring, or is slowed by a tack, some margin of lift is needed to prevent excessive leeway while speed is increasing. Also, in heavy weather, when the boat speed is limited by waves and Froude drag, the loading on the keel becomes higher than that computed above, so some margin of lift is needed.

The analogy with an airplane is quite valid. At take-off, maximum lift is needed at low speeds and fairly high angles of attack. At cruise, minimum drag is needed at high speed and low angles of attack.

One other interesting and perhaps instructive use of the cross plot of Fig. 4 is shown on Fig. 5. If a hull and keel is postulated such that the aspect ratio is 2.5 and the area ratio is .3 we find ourselves at point 1 with a value of C_L/λ equal to a bit over .027. If analysis shows that this rather narrow keel does not provide the lift required at reasonable leeway angles, the keel can be made longer in the fore and aft dimension so as not to increase draft, and with an addition of about 17% in length, we arrive at point 2. Note that the system aspect ratio has gone down but both the lift curve slope and the keel area have gone up, so the available lift is up dramatically. A further step takes us to point 3 with an addition of 40% in the length of the keel. Two other examples are shown, one that starts as aspect ratio 2 and another at 1.5.

CONCLUSIONS.

1. Values of the lift curve slope for many types of hulls and keels can be found approximately from these curves. The applicability is limited to low Froude Numbers. (Data taken at $N_F = .2$; $V/\sqrt{L} = 1.1$).

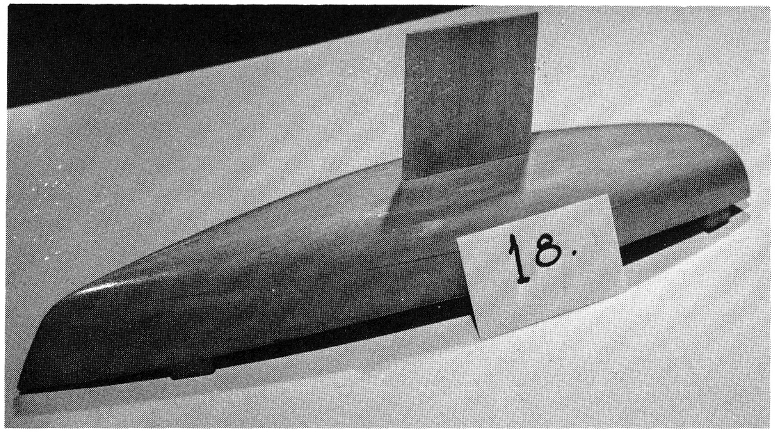


Fig. 10

2. The lift curve slopes conform reasonably well to predictions by aerodynamic theory for a wide range of aspect ratios despite the presence of the free surface.
3. Lift curve slopes can be determined approximately for fin keels and hulls over a considerable range of Keel plus Rudder to Total Lateral Area ratio. The data confirm the fact that most of the lift comes from properly shaped fins, and little from the hull.

In using this information for design, it is important to keep in mind that the lift needed is determined by the sail plan and hull aerodynamics, and not by any arbitrary requirement for high lift to drag ratios.

It is evident that the plotted data represents an oversimplification of the lift problem if all the variables are considered, and if great precision is required. Our effort has been to provide a means of estimating, within practical accuracies, the lift curve slope for as wide a range of hulls as possible.

We hope this work will be of interest and use to AYRS members, and perhaps stimulate further work elsewhere. We welcome any information which could be added to our presentation of the data to expand it into areas not covered by our tests, or to correct any inadvertent errors.

THE WHIFFLETREE.

This is, essentially, a very light cross pole on which there are three crude pivots such as places where light line is tied on. The pole can be straight across or have an angle in it. The three pivots must, however, not be in the same line but must be angled to each other. The amount of the angulation determines the sensitivity of the test and also its stability.

If the three pivots are in a straight line or only a little angled, the variations in resistance with speed may not be appreciated. If each side pivot is angled back at 30°, one hull can have twice the resistance of the other at one time and tests can still continue. If each side pivot is angled back at 45°, stability is the greatest but probably unnecessarily so. The greater the back angle, the less the sensitivity. At a guess, back angles of 15° and 30° should cover most hulls.

A refinement might be a forward pointer on a scale to measure the exact comparison in resistance.

THE METHOD.

Two models are made of exactly the same length, weight and wetted surface. That one which has the lesser resistance when towed by whiffletree will be the faster yacht on a running course.

If it is wished to compare models with different wetted surfaces, the picture is more complicated. The two models have to be compared in resistance, by whiffletree and then relative stabilities and sail areas have to be found. If the sail areas to wetted surface ratios are the same, the yacht with less resistance by whiffletree should have the greater speed.

It is possible, too, that a curve of residual resistance could be obtained by towing a model against a plastic sheet of its own surface, as described by Edmond Bruce and taking the speed. The approximate resistance of the skin can be calculated from the Schoenherr curve and the relative resistance at different speeds will give a curve of residual resistance without figures of quantity.

I suspect, too, that finding the relative resistance of a newly designed hull against one of known resistance, as taken in a test tank could produce valuable figures but the exact mathematical juggle is not to hand at the moment.

SUMMARY.

Whiffletree research allowed Nathanial Herreshoff to be the supreme designer of the 19th Century. Its use could be of great value to any yacht designer who has no ready access to a test tank.

I myself feel sure that, by appropriate thought, methods can be devised to make whiffletree research give curves of resistance for yachts only marginally less accurate than the commercial towing test tank.

you sail where the thermals serve pretty regularly. But if you sail where the airs can get pretty light and vagrant quite often, then you have some food for thought. Making double chines is more work - but may be worth it for you.

I am continuing to test shapes of various simple forms, and will report further on what might seem promising. We are, of course, all looking for the 'funky' form - something that can be made up out of ply sheet on a week-end and that will go like crazy in all conditions. Is there one? Perhaps. Or at least, the 'whiffletree' tests will suggest that some may be a little better than others.

WHIFFLETREE RESEARCH

or, How to Become a Top Yacht Designer.

by John Morwood; Woodacres; Hythe, Kent, England.

As an Editor, one hopes to give the right emphasis to everything and especially to pick out those real gems of information which can mean so much to people. Somehow, at its first presentation, I missed the essential value of the article by Dick Andrews on comparative testing of yacht hulls. I now want to make good my mistake.

A 'Whiffletree' or 'Whippletree' is the cross beam to which the traces of a horse are attached when plowing to equalise the pull on each. Dick's sketch shows this nicely. The word is fairly old and is derived from 'Whip' or bendy.

The method of yacht research is to tow two models in a pond from the ends of a cross bar, pulled from its centre. The model with greater resistance pulls back against the other. The best and most used way of towing is by a springy fishing rod which allows the most delicate adjustment of strain.

It was only when Dick sent me the article which follows this one and I started to design the whiffletree that I realised that here was a research tool which would make any interested person a top yacht designer.

Yacht designing is an empirical art. Over the years, certain essentials have been derived and have been put down in books. From these, one can sit down and draw out the lines of a yacht which will sail well but is unlikely to win races. However, the race winning yacht nearly always has a hull which has been tested in some way in model form and found to give less resistance than other very similar yachts. One can, of course, have the model expensively tested in a tank -- or one can use a whiffletree.

It has always been a source of wonder to me why the British had never won the America's cup in all its long history. I now know. Old Nat Herreshoff used a whiffletree to test his models while the British designers designed only by eye and experience. I once read somewhere that 'Old Nat' towed models in ponds with a fishing rod but had no details. At the time, I thought he might have been looking for waves and hollows along the hull. Now, I feel sure that he was doing comparative resistance tests, but would like to have this confirmed.

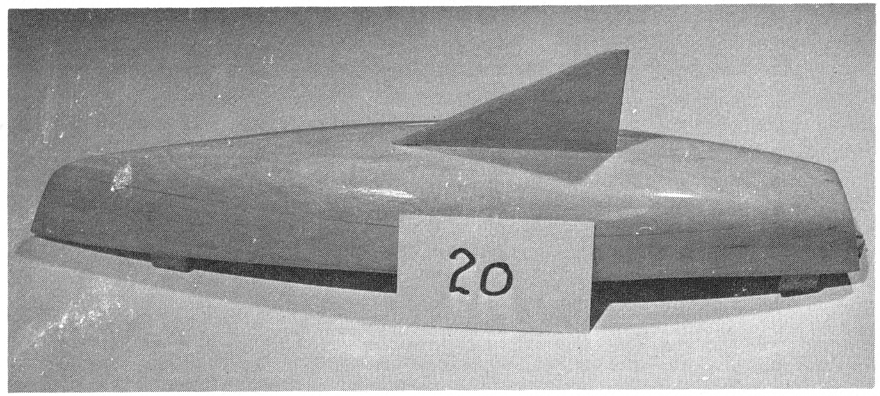


Fig. 11

APPENDIX I - A SMALL TOWING TANK.

In late 1970, a towing tank was built in a corner of our laboratory for use with laminar models. It is 16 feet long, 2½ feet wide and 1½ feet deep. (See Figs. 13, 14, and 15). Since then much time has been spent experimenting with instrumentation and testing methods in an effort to reach a point where the data could be trusted. We began with a falling weight system, and in so doing, built several low friction pulleys, and organized an optical system for measuring speed. Because of limitations in the ceiling height, and doubts about the method for testing hulls with sideways forces, a rather more conventional carriage and drive was built. This system is now in use, and is shown in the photographs.

The drive system is powered by a direct current motor, shunt wound, driven by two bridge rectifiers, a fixed one for the field and a variable one for the armature. The motor drives a cog belt system with several different speed ratios available. It is important to have the motor running reasonably fast to avoid variations in carriage speed within the frequency range of the force sensing devices. (Fig. 16).

The carriage is a simple aluminum frame running on machined plastic wheels mounted on small ball bearings. The track is a steel tube mounted on one side of the tank, and carefully leveled and straightened with respect to the surface of the water. The other side of the carriage runs on a flat wooden rail secured to the edge of the rank rim and similarly leveled. The

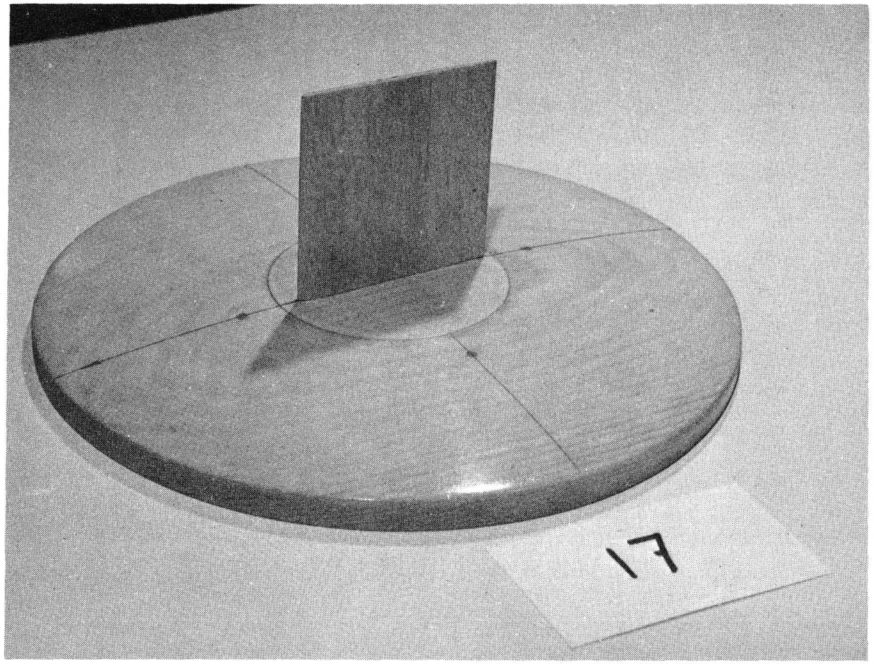


Fig. 12

carriage is clamped to, and driven by a loop of steel tape that runs over the driven pulley on the drive end of the tank, and an idler pulley on the other end.

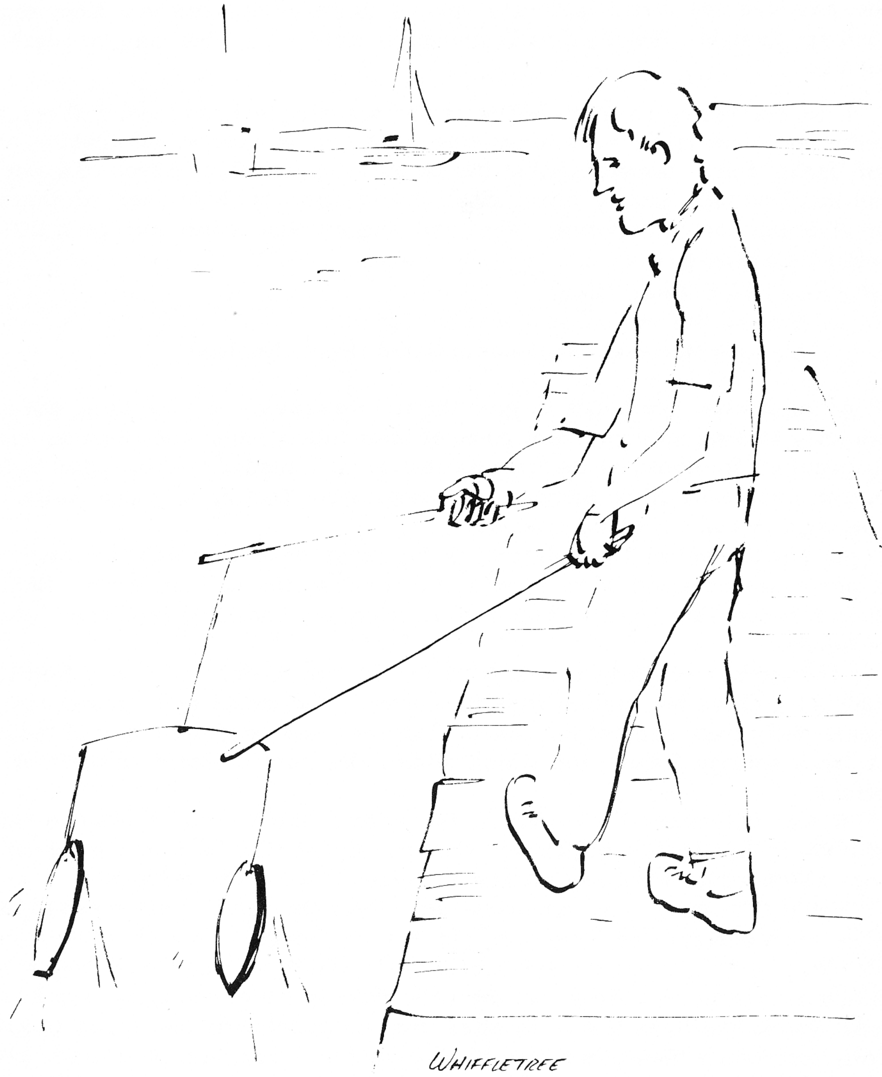
The overall drive and carriage system is barely satisfactory from the point of view of steadiness of speed, both short term variations within the course of a run. and longer term difficulties with resetting the same speed.

The tank is simply a robust wooden box, lined with plastic impregnated nylon material formed into a bag, tucked around the rim and glued to the various windows. A drain is fitted to simplify the water changing procedure. The lining has not been entirely satisfactory because of the difficulty with the glue joints at the windows, but otherwise the tank has not given trouble.

INSTRUMENTATION.

The instrumentation currently in use serves three purposes:

1. Carriage speed measurements are made with an electronic counter counting milliseconds between two switch contacts placed on the side of the tank, precisely one foot apart. The counter is an old one with more than a hundred vacuum tubes in it, so we are very nervous about the inevitable day it quits and we have to find the trouble. But so far, the speed measuring system has been very satisfactory. Of course, it measures the average speed over only one foot of the carriage travel, but both the resolution and repeatability are better than adequate, and the selected foot is near the end of the run where equilibrium conditions exist.



as they are almost identical in most respects. However, when walking along the dock with them rather slowly, the single chined boat tended to drop back. In repeated runs at a slow pace, it became fairly obvious that the single chine form will not ghost as well as the other for a given sail force. Where one takes it from there, is one's own choice. The simpler shape is well worth it if you are not going to try to ghost along much - or if

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6. Letcher, J. S., Jr., "Sailing Hull Hydrodynamics, with Reanalysis of the *Antiope* Data," Society of Naval Architects and Marine Engineers, 1975.
7. Morss, Henry A., Jr., "Forces and Angles in Sailboat Performance," Society of Naval Architects and Marine Engineers, 1976.
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WHIFFLE-TREE TESTING OF BOAT HULL MODELS by Dick Andrews;
25 Audubon Drive; Ossining, New York 10562

A very simple way to test the comparative merits of two model boat hulls is to tow them side by side from a "whiffletree" or balanced yoke. This has been done over the side of a motor boat, or in a running brook. I prefer to use a pole or stick and walk along a pier as shown in the sketch, so that I can vary the speed at will and can also readily observe the models.

Whatever the dimensions of the models, the weight should be the same. My models have not been complete boat forms, but represent chiefly the immersed part of the hulls; thus I have made them rather quickly from solid clear pine dimension. These float as if loaded with superstructure. If one model weighs less than the other, as may be shown simply by hanging them in the air on the yoke or whiffletree - then one can add weight to balance them.

As an example, a friend of mine made a flat bottomed hull which was described as being a real bomb under sail. I had not seen the boat but made a model according to description and dimensions given, to a scale of an inch to the foot. (This made a model 24 inches long.) I wanted to see if exactly the same shape - except for double chined rounding - would be comparable. So the first model was laid on a pine blank, traced around with a pencil, and a second model made to the same size and shape. Then the single chines were whittled away (using a belt sander) to a double chined form. The wood models were given a coat of shellac; sanded; shellaced again; sanded again finer - and thus both water-proofed and given a smooth surface. The lighter double-chined form (as more wood had been removed in making it) was given a nail on the deck at the general center of buoyancy, and small washers put over it until both hung level from the yoke.

The tests were made by drawing them along through the water and simply watching to see which went ahead. In the off hand I held a stick to prod them around or untangle them as necessary. One can walk very slowly to simulate quite light air, or trot along for a good blast.

These tests are strictly qualitative. There are no gauges or dials to read. If the models are very much the same form except for some minor variation, you may naturally find rather little difference in their performance. However you can observe, and if you take your time and make repeated runs, you will begin to notice qualities.

In the test of the models described here, I found almost no significant difference in the performance of the single-chine flat bottomed form, and its variant with the extra chine - at most speeds. This is not suprising,

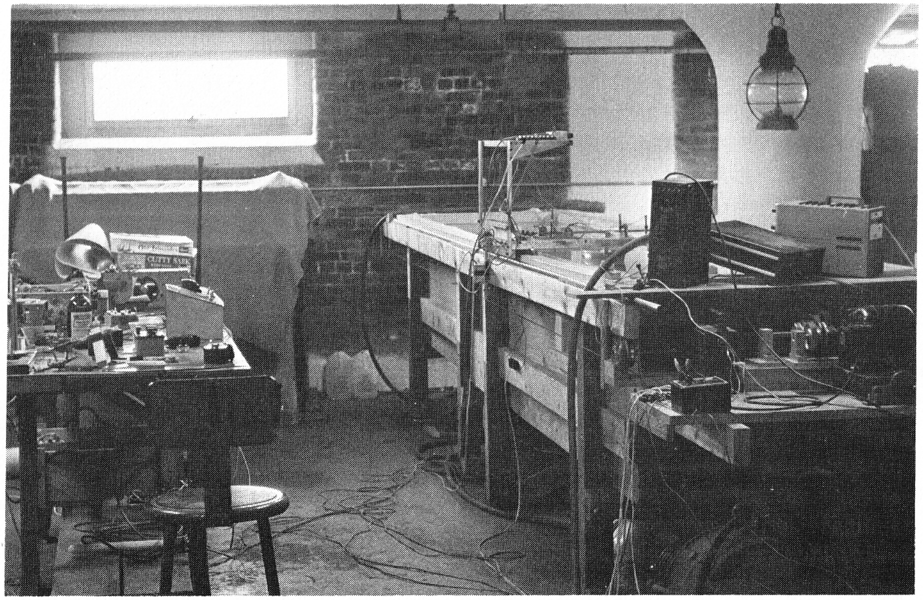

Fig. 13

2. The force measurement is made with a single Endevco strain gage probe. Full scale force reading is 20 grams at which point a 10 volt bridge provides an output voltage of about 750 milivolts. The readout is a digital voltmeter with 4½ digits which will resolve a tenth of a milivolt, which is more than can be usefully used. In a situation like this, where the drag force is on the order of one percent of the weight of the test hull, and the moving carriage cannot be made to move with absolute smoothness, a substantially irregular signal output is unavoidable without some damping introduced somewhere in the system. After a variety of efforts with mechanical and electronic damping, a satisfactory system has been worked out using some of each. The mechanical system is an extension of the force probe that is partially immersed in a small reservoir of 100,000 centistoke silicone oil. The electrical system is simply several hundred microfarads of capacitance across the bridge output. The damping needs to be variable because at high carriage speeds, time constants need to be shortened to get any equilibrium data. A sample recorder trace of the output of this system is shown in Fig. 17. The peak at the beginning of the track is the result of the acceleration force on the hull which declines to a steady value toward the end of the run. Incidentally, the recorder is a relic of the optical system for speed measurements and is not adequate for these force measurements due to zero drift, inadequate resolution of the trace, and drift in gain. The force probe, bridge power supply and readout DVM have been repeatedly calibrated using secondary standard weights and the best techniques we can devise, so we are satisfied with the accuracy of the force readings.

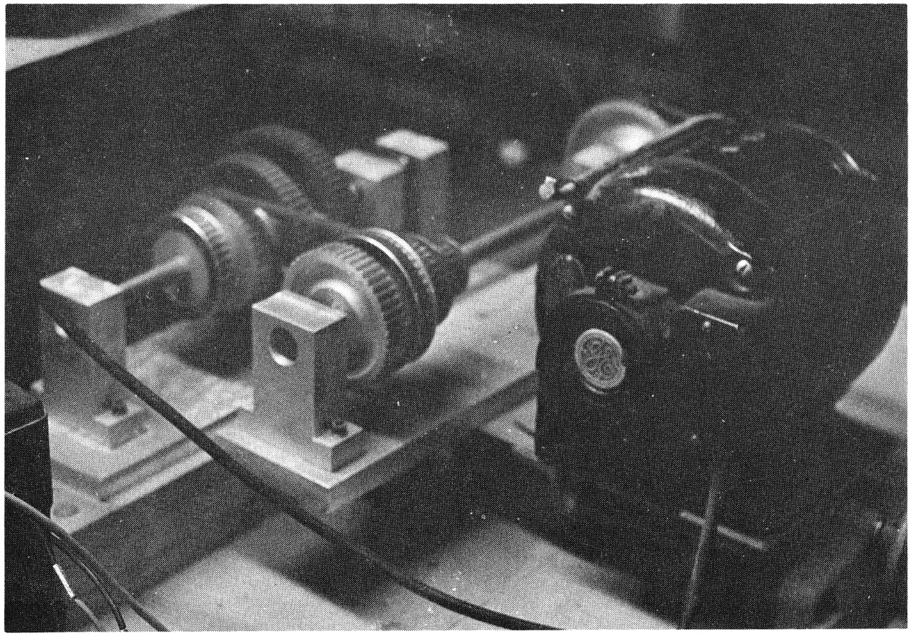

Fig. 16

3. A direct measurement of hull drag angle is made using a system of synchros mounted on an adjustable plate, with the hull attached to it with two movable arms that form a parallelogram. (See Fig. 18). The angle of attack of the hull for the run is set by setting the plate that carries the synchros. One synchro is for the angle measurement, and the other simply serves as a low friction bearing. A 400 hz voltage is applied to the primary winding of one of the synchros. The output of any one of the secondary windings is a sine function of the angle of the rotor from some reference point. The synchro is adjusted to give zero output with the angle of attack set to zero, and the arms of the parallelogram directly across the tank. The output is read using the DVM, and from the voltage reading, the synchro angle can be deduced. Because of the fact that the synchro body turns with the plate that sets the angle of attack, the drag angle is the sum of the synchro angle and the set angle of attack.

From a practical point of view, there are several drawbacks to this system. The angle that the hull assumes is very sensitive to small changes in carriage speed, turbulence in the tank, and straightness of the carriage track. It has a comparatively long time constant and is underdamped, so it tends to overshoot. The wooden bumpers shown in the photographs serve to position the hull near the test point so as to minimize the overshoot and settling time. In spite of all this, some reasonably consistent, repeatable and reasonable looking data have been obtained.

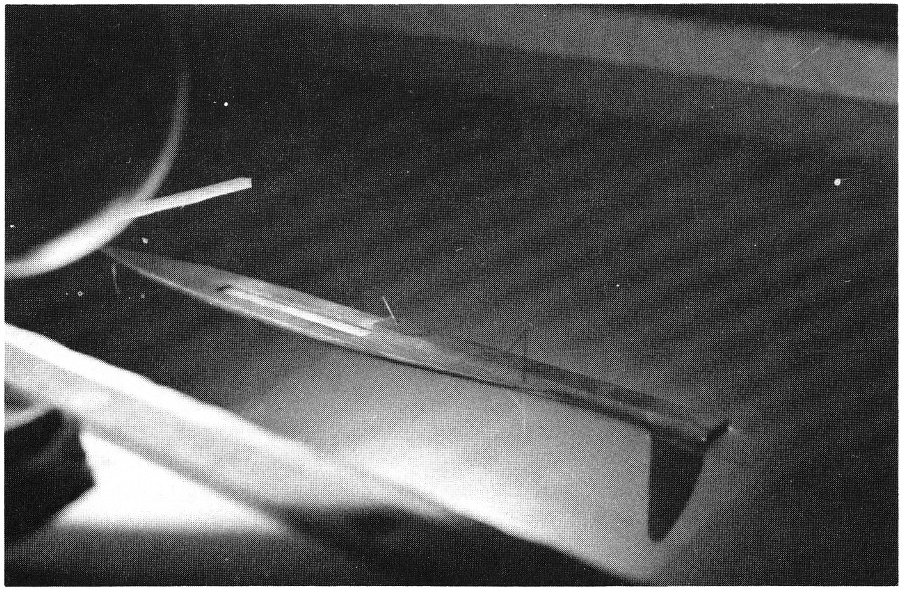

Fig. 21

A similar test was run on a thin foil, similar to an 8% NACA four digit wing section. Permanganate crystals were attached to the trailing edge of the foil. At angles of attack in excess of 9 degrees, the dye traced a path upstream on the suction side of the foil to the separation point. It is a remarkably clear demonstration of the existance of circulating currents in the separated zone. Here, we have adopted a limit of 7 degrees as the maximum for reliable results.

Of course, in the process of doing hull and keel tests, both of these criteria are exceeded some of the time. The important fact to keep in mind is that when they are exceeded, separated flow conditions may exist, and the results should be treated with caution. This is specially true of drag data where large errors can occur.

The tests reported in the lift coefficient investigation were within the criteria with the exception of the *Constitution* hull, as noted.

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2. Whicker, L. F. and Fehlner, L. F., "Free Stream Characteristics of a Family of Low Aspect Ratio All Movable Control Surfaces for Application to Ship Design." David Taylor Model Basin Report 933, 1953.
3. Abbot, I. H., and Doenhoff, A. E., *Theory of Wing Sections*, Dover Publications, Inc. 1959.
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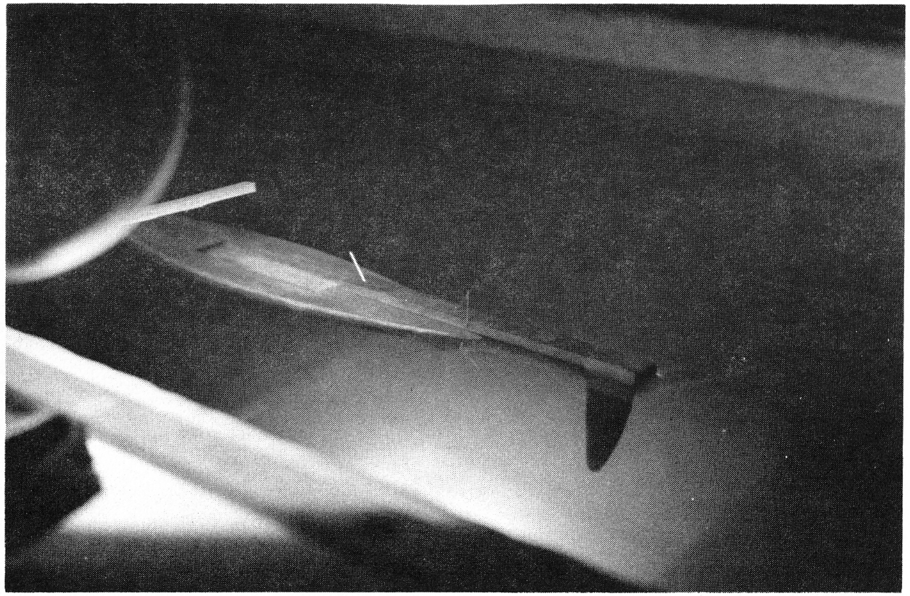


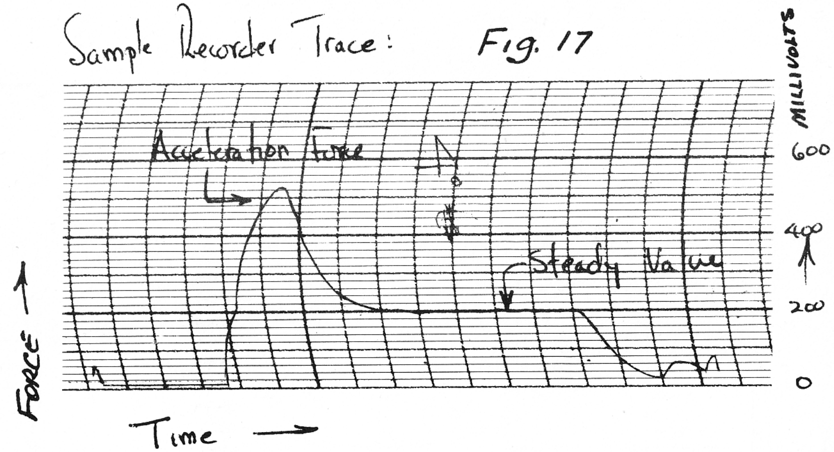
Fig. 20

A series of six models was made, each one foot long, with semicircular sections and circular arcs for longitudinal sections. The ratios of beam to length for the six models, and the convergence angle at the stern are given below. (See Fig. 19). (This angle is measured in the vertical plane between the hull on the centerline and the horizontal water surface.)

Model	Beam / Length	Convergence Angle, Degs.	$\nabla/L^3 \times 100$
1	1/3	36.8	2.6%
2	1/4	28.1	1.26%
3	1/5	22.6	.82%
4	1/6	18.9	.60%
5	1/8	14.3	.33%
6	1/10	11.4	.21%

The models were prepared with several small crystals of potassium permanganate imbedded in beeswax around the midsections, and towed at low speeds. The crystals left easily visible trails in the boundary layers, and it was perfectly clear from visual observations when separated flow occurred.

Models 1, 2, and 3 all separated. Model 4 separated over a very limited area at the extreme aft end. Models 5 and 6 did not show any separation. We have adopted a limit of 15 degrees as the maximum allowable convergence angle at the stern of test models for results to be considered reliable. (See Figs. 20, 21).



We hope to change the system in the future to a system using three force probes and a good three channel recorder. One probe will measure drag. The others will measure sideways forces at bow and stern. The results should be better in terms of repeatability and general convenience, and in addition the center of lateral force can be determined, which the present system does not allow.

APPENDIX II - SOME BACKGROUND.

There is widespread and entirely justified doubt about the accuracy and usefullness of data taken from laminar models and extended to full size. This doubt centers around one important fact. Laminar boundary layers do not behave the same way that turbulent ones do in one major respect. In diffusing situations, that is where the relative fluid velocity is decreasing and the static pressure is increasing, laminar boundary layers are more prone to separation than turbulent ones. (Ref. 8, Chap. 2). This is the precise situation along the after part of every boat.

It is intuitively obvious that when a boat moves through the water, all the water ahead of the hull, in the prism that forms the path the boat is taking, must move away as the hull progresses, and that somehow water must flow into the trough left behind. Actually, particles of water make paths that are roughly circular. As the boat approaches, a particle just off the center line moves forward a bit, then outboard, then curves aft as the midship section goes by, curves inboard, toward the stern, and finally completes the circle by returning approximately to its original location. If the flow were entirely frictionless, the particle would return precisely to its original place. The first half of the circle subjects the particle to accelerated flow, and the second half subjects it to decelerated flow. It is in the second half of the circle that the water is flowing into the trough behind the moving boat.

This simple picture is considerably complicated by the realities of flow with friction. At the surface of the moving hull, a boundary layer always forms. This is a layer of water that moves with the hull. It is thin at the bow; and thick, relatively, at the stern. The film of water right on the surface of the hull moves at the speed of the hull. Successive layers move

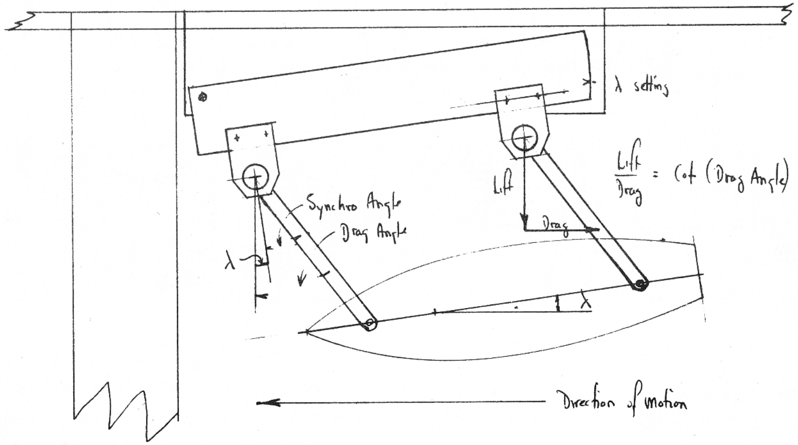


Fig. 18

slower until outside the boundary layer the only motion is the circular one described above. And, of course, the presence of the boundary layer affects the circulating flow outside, and some of the circulating flow is superimposed on the outer layers of the boundary layers.

If a boat is long and thin and well shaped, the flow patterns are relatively simple. The boat pushes the water away, and the stern draws it together again. The wake, (not referring to surface waves now), consists only of water that was in the boundary layer that, because of friction with the hull, acquired some velocity in the direction of motion of the hull. This moving water in the wake possesses the energy that was expended in the skin friction of the moving hull.

If a boat is very plump in the stern, or has a submerged flat transom, it is intuitively obvious that the water simply cannot make the converging turn, and it separates from the hull. Behind the separation point is a babbling brook of water that flows with the boat. Here again, all the energy in this relatively large turbulent stream represents real drag that the hull experienced in its motion.

In the situation where the boat is of moderate plumpness aft, and there may be separated flow, major doubts about our model testing procedures arise. In turbulent boundary layers, that is at Reynolds Numbers higher than about 3 x 10^6, energy is diffused through the boundary layer and so is available near the surface of the hull. Thus the flow is better able to cling

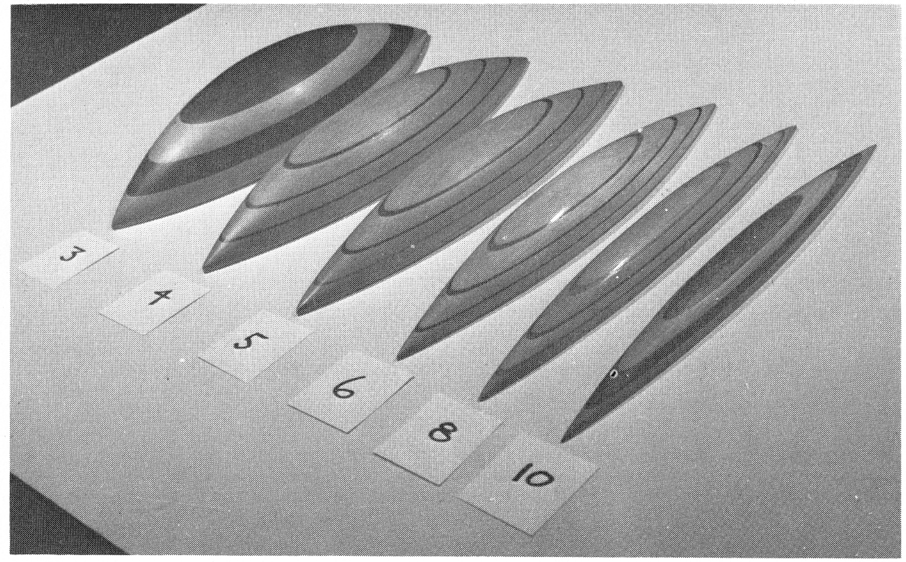


Fig. 19

to the surface of the hull, and make the turn at the stern. In laminar boundary layers, at Reynolds Numbers less than 3 x 10^5, energy diffusion through the boundary layer is much less, so the flow is more likely to separate. If separated flow does not occur on a full sized boat, it may or may not occur on a laminar model. If it does definitely occur on a full sized boat, it will surely occur on a laminar model, and in a different location. On the other hand, if separated flow does not occur on a laminar model, it certainly will not occur on a full sized boat.

This last situation is the only one that can be handled analytically with any confidence. With laminar models, separated flow simply cannot be allowed if the results are to be extended to full size. If the shape of a boat unavoidably involves separated flow, there is no way that we know of that a laminar model can be used.

APPENDIX III - LAMINAR SEPARATION CRITERIA.

The first problem that we worked on with the tank was the problem of determining some usable laminar separation criteria. The effort was entirely experimental in nature, since analytical methods are of doubtful accuracy, and mostly beyond our computational power.

There are two areas where these criteria are needed. One is at the stern of a hull under test, and the other is on the suction side of any foils that are running at some angle of attack; such as keels, rudders, or centerboards.