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AYRS

SPEED SAILING

THE AMATEUR YACHT RESEARCH SOCIETY
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The Amateur Yacht Research Society is a Limited Company, and a registered educational charity. Membership is open to anyone interested in the improvement of yachts and equipment by the use of research and development.

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Note:
Bruce Number = square root of sail area, divided by cube root of weight.

$$Br = \frac{\sqrt{S.A.}}{\sqrt[3]{Weight}}$$

EDITORS NOTE

by

Michael Ellison

Our Chairman, Dr. R. Bennett did not stand for re-election to Parliament and now hopes to have more time for sailing. He is listed in the recent honours list as a new Knight Batchelor and is now "Sir".

We are most grateful to Professor W. S. Bradfield and Richard Boehmer for their magnificent contributions to this publication. In letters to me, members have asked for more short, sharp reports and ideas and I have tried to include a few. Most members are busy and editors get tired – if you, yes YOU! wish to report on a new idea that you have tried or noticed some-one else trying, please sent it in – but not scribbled on both sides of twelve sheets of paper by the tame spider you use as a secretary. I read it all and re-type most of it but probably the hardest job is to reduce the length without altering the meaning or value of your contribution. Contributors names are given so that you can write to them if you are working on a similar project or idea, if you expect a reply, a self-addressed envelope always helps!

Cdr. George Chapman, R.N. kindly sent the report of the 1978 Portland Speed Event, I am sorry this is late, but it is relevant to Prof. Bradfield's work. Note that the Navy gave permission for the course to be laid in Portland Harbour but John Player paid the cost. The 1979 event will be held from 13th to 20th October inclusive, but there is no sponsor and therefore no prize money. "Slingshot" will again be campaigned by Karl Thomas from U.S.A.

Unfortunately, Eric Tabarly did not win the race from France round Bermuda and back to France with his hydrofoil stabilised "Paul Ricard," his position was second to the French trimaran "VSD" but the time difference after the double Atlantic crossing was under six minutes. Hopefully this will encourage wider interest in foils.

HIGH SPEED SAILING VEHICLES

by

Professor W. S. Bradfield
(SUNY at Stony Brook, Long Island)

A Paper Presented at the New York Metropolitan Section
The Society of Naval Architects and Marine Engineers
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January 11th, 1979.

ABSTRACT

A recently established international competition has encouraged straight-line yacht racing over very short courses in flat water with the strongest winds available. The object of this activity is to stimulate the quest for unrestricted sailing vehicle designs which will produce flat out speed under relatively safe and controlled conditions thereby pinning down and quantifying design factors governing high speed yacht performance. This competition has produced a few surprises and some novel and ingenious designs—some successful. The object of this paper is to discuss and compare some of the novel ideas which have developed into successful drag racing yachts during the past five years. Performance predictions are compared with measured performance in outstanding cases.

INTRODUCTION

If there were a slogan chosen to typify the radical high speed sailing vehicle of today, it might well be: GET THE HULL OUT OF THE WATER! Because that is the direction in which designs are heading in order to achieve outstanding performance under sail. In fact, if you view the concept of the sailing vehicle as a practical assemblage of a minimum number of useful subsystems, one fairly rational design might appear as shown in Figure 1. The three identifiable subsystems shown as Figure 2 might be called: i) the Thruster-Lifter (or sail); ii) the Payload Container (or hull); iii) the Hydrodynamic Stabilizer. Not shown but obviously equally as important is the control subsystem. Everyone recognizes that there are a lot of variations and combinations of these ingredients in any existing boat. For example, the conventional sail thruster as applied to a standard hull when heeled produces a downforce plus thrust not an upforce plus thrust as shown in Figures 1 and 2. The standard hull is a hydrodynamic lifter (and drag producer) as well as a payload container; a daggerboard and rudder may even be destabilizing and they aslo may be equipped with lifting foils; etc., etc. Control systems may be anything from the (seemingly) thousands of elements of exposed running rigging of a square rigger to the beautifully simple aircraft type internal pushrod control systems typified by the most advanced of our currently operational radical sailing vessels. A good example of the latter useage is in the patented[1] Amick "flying boat" (figure 2) which has just completed (December 1978) preliminary testing. As indicated by Figure 3,[1] this vehicle is indeed designed to get the hull out of the water relying on aerodynamic lift, propulsion, and control and on hydrodynamic side-force holding (Compare Figure 1). The tests to date indicate that the boat will go to windward and tack hullborne. A structural failure precluded completing the preliminary tests so that the airborne performance is by no means the first of such vehicles to be tested. It is certainly the most professionally designed and executed. This general class currently includes wind surfers, kite and hang glider propelled catamaran hulls, and a hydrofoil lift assisted proa, Exoplane,[2] all of which have competed in annual international speed trials in England the last few years. None (excepting the wind surfer) has lived up to its predicted performance as yet. It is significant that they have been built and tested and that the development work on the concept continues. However, less radical boats have been and continue to be more successful in measuring up to their predicted performance potential.

The most successful of the more conventional boats is Crossbow II, a 60 foot biplane rigged, staggered hull catamaran[2], designed by R. McAlpine-Downey and owned by T. Colman. Her maximum average speed over a ½ kilometer course was officially timed at 34.4 knots in a wind reportedly gusting to 30 knots (force 7) in Portland Harbor in October 1978. The fastest of the smaller boats at present is [nf]^2 a 23 foot canard hydrofoil with a conventional rig designed by mechanical engineering students at SUNY Stony Brook, Long Island. Her best run over the official ½ kilometer course averaged 24.4 knots in a wind measured at 14 to 16 knots (force 4), in Port Jefferson (Long Island) Harbor in November 1978. Photographs of [nf]^2 are shown in reference 3. Among the smallest boats, the ubiquitous wind surfer with its handkerchief sail (70 ft^2) was officially timed in 1977 at an average speed for ½ kilometer of 19.1 knots! The wind was reported to be force 6 for these runs.

Each of these vehicles relies on different design approaches to attain high speed. Crossbow is quite conventional in her use of displacement hulls although they are very high fineness ratio and very lightly loaded. She has a moderate spread of sail for such a big platform and her biplane rig and catamaran configuration are designed to minimize heeling and pitchpoling moments and maximize righting moments to permit maximum utilization of thrust in strong winds, Obviously a very successful design for her intended use. The wind surfer is a planing hull with aerodynamic lift assist. Sailing technique requires heeling the rig to windward in strong winds (as in Figure 1) and this brings aerodynamic enhancement to the planing capability literally getting the hull out of the water momentarily at high speeds. [nf]^2 is a hull lifting hydrofoil conservatively designed specifically for speed trials. This design relies on a large beam to length ratio and a modest amount of foil aileron for heel control. Pitchpoling is controlled by the forward stabilizer. The 24.4 knot speed was achieved in force 4 winds at a gross weight of 960 lbs. and 300 ft.^{2} of sail heeled to leeward.

These three fast boats are "conventional" in the sense that they have been on the scene for nearly a decade while being developed. It's not surprising that they outperform the "radical" boats which are relatively untried. The surprising thing is that the radical boats have developed at all. And a most important reason is that they have been provided with an incentive for development by the International Sailing Speed Trials organised by the British R.Y.A. which encourages the testing of new design concepts under well controlled conditions. In this context, the serious designer (professional or amateur) has an opportunity to obtain accurate performance data to feed back into his design and developement work.

PERFORMANCE MEASUREMENT

In the early 1970's a few English Royal Yachting Association members led by Peter Scott and including Beecher Moore, John Fisk and other well known racing yachtsmen decided it would be a good idea to find out just how fast a sailing vehicle could be made to go on "soft" water no holds barred. It would stimulate innovative thinking and design, they believed, and it would circumvent the strangle hold on design innovation which the racing rules tend to impose. The only rules were that the speeds should be measured over an accurately surveyed course of not less than half kilometer; the timing should be done by officials with stop watches; the vehicle should be capable of starting from rest and proceeding under wind power only; at least one crew member should be on board during the official runs; there should be no stored power on board; and the proceedings should be under the supervision of an Official Observer appointed by the National Authority. This admirably simple plan was put into operation in Portland Harbour at Weymouth, England, in 1972. Official Speed Trials have been held in England annually since that time. Subsequently, Official Speed Trials have regularly been held in the U.S. on Long Island or in Connecticut. Unofficial trials have been held in California as well.

The essence of the speed trials competition is the course itself. So far, these have been laid in two ways as shown in figure 4. The British course has been set by the Navy in Portland Harbour and consists of a ring of accurately positioned buoys at each number of a clock face. The centre of the clock face is also void. With this geometry the helmsman is at liberty to choose his preferred course relative to the wind direction. This elaborate layout is expensive and difficult, if not impossible to set up without substantial financial and organisational support.Lacking this, the U.S. contingent propose course b) on figure 4 which was accepted by the Internation Committee after due consideration. It was also later adapted by the English as a "flat water course." In taking data, all runs are timed by 4 watches to the nearest 1/10 second. Wind, tide and (sometimes) sea surface conditions are recorded. And, usually, the course is set in sheltered waters.

Over the period of six years, during which data has been taken, the boats sorted themselves out by type and by size. conventional monohulls dropped out early.Theysimply have not shown the heel control necessary to cope with the wind force required for record speed. The exceptional case is the sail powered surf board, which, was pointed out, is sailed heeled to weather. This is necessary for heel stability and it also produces an aerodynamic lifting component which in this case is significant compared to the gross weight of the vehicle. Its configuration approaches that of figures 1, 2, 3. It is very impressive that this vehicle averaged nearly 20 knots over a half kilometer course in a wind averaging nearly 24 knots. It is largely attribute to the skill of the sailor in controlling this mustang but it emphasises the possible advantages of the uses of aerodynamic lift.

Among the multihulls, none has been able to approach the performance of the MacAlpine-Downie designed Crossbow I and II from the very first year of the trials. Partly as a result of the diminishing interest caused by this domination of the competition, racing classes defined by sail area limits were innitiated. The established classes and currently fastest officially timed speeds are shown as Table 1. Within these classes, the three hydrofoil configurations seemed to have bunched together between 23 knots and 25 knots during the last three years. However, reference to table 1 shows that sail area to weight ratio for all hydrofoil vehicles shown there is very close despite the sail area differences.

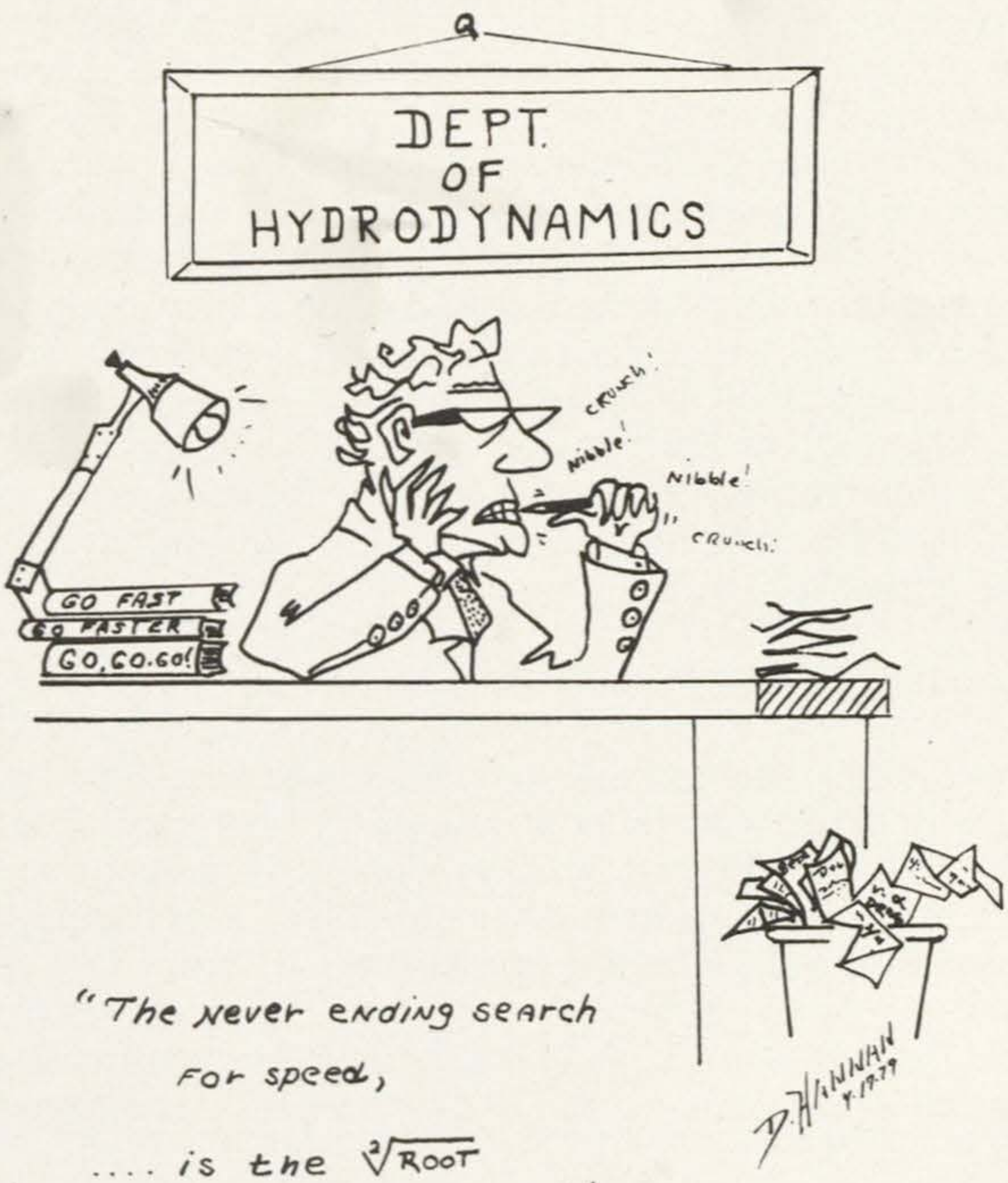
PERFORMANCE PREDICTIONS

As in most other areas of vehicular engineering, performance prediction of sailing vehicles is much easier and cheaper than performance measurement and so there exists a fairly large body of sailing yacht performance theory (which hardly anyone reads). A fairly complete bibliography in this area is included in References 4 and 5. Performance predictions of "radical" vehicles as discussed herein should be especially simple because we're dealing with vehicles having positive attitude control (pitch and heel); travelling over short straight courses; in sheltered water; and the wind and current speed, direction and steadiness are determined. The transit times in these courses is of the order of 25 to 50 seconds for current boats. With the foregoing restrictions on operation, performance predictions reduces to equating thrust to drag while keeping an eye on the vehicles' inherrent limitations of righting moment capability and sideforce holding. The equilibrium motion state can then be determined analytically or by iteration depending on how sophisticated the mathematical model is permitted to become. Manual iteration on a relatively crude mathematical model of Crossbow I produced the results[6] shown in figure 5. The agreement between predicted and measured results was considered satisfactory. therefore, in in accordance with the prediction model, Crossbow's speed can be explained simply by saying that she is a big, well sailed, lightweight, high fineness ratio, "monohull" with a high degree of heel stabilisation. Her improvement in performance since 1972 can be explained mainly as a result of lowering her centre of effort while maintaining her inherrent righting moment and thrust potential. Also, final developments of sail control, steering, tuning, and technique have taken place. As a conventional boat, her performance isn't likely to improve much in this writer's oppinion.

The performance prediction for $[nf]^2$ is somewhat laborious due to the ladder configuration[3] of her multiple element surface piercing foil system. However, the analysis was performed for the "design condition" (with results shown on figures 6 and 7); namely, acceleration from rest on a course 105 degrees to the true wind in a wind strength of force 5. these results give some insight to the inherrent performance limitations on the vehicle. Hull hydrodynamic drag is not included below take off speed but is included in the parasite drag term for all speeds. The most significant feature is the very rapid increase in drag beyond 20 knots boat speed. This is due to the rapid increase in sail side force relative to thrust (figure 7) which necessitates using more and more foil heel control with the attendant drag increase while the thrust remains essentially constant. It is apparent that a boat speed of 25 knots, 70% of the drag is due to stabilizing the vehicle and dragging it through the air and the situation rapidly worsens if you further increase the speed. Only 30% of the drag is due to supporting the payload.

If a rig coefficient of unity is assumed[5] and the resultant thrust versus boat speed curve is overlaid on the drag curve, an equilibrium speed of about 29 knots is indicated for the C-Class configuration (Figure 7).

This type of ex post facto performance analysis is more qualitative than quantitative but its usefulness lies in that it points up with considerable clarity some design areas where improvement must take place in the next generation of foiled vehicles.



CONFIGURATION DESIGN OPTIMIZATION

It seems clear, if the foregoing analysis can be considered typical of foiled vehicles, that their failure to reach the expected performance potential is essentially a control system failing. Parasite drag is obviously a factor but it's easy to eliminate most of that by judicious fairing, at least conceptually (e.g. Figure 1 and Figure 3). It doesn't really pose a serious design problem.

The design challenge is in countering heel, pitchpoling, and sideforce holding most efficiently in terms of drag to weight ratio. This has to be done while maintaining vehicle control despite the necessity for operating in a condition where the sideforce is probably always large compared to the thrust (Figure 7) and the thrustline is high relative to the c.g. position. The kite concept (Figure 2) handles this latter problem by automatically directing the aerodynamic and hydrodynamic forces through the vehicle c.g. The first generation of seriously thought out vehicles of this type is in fact currently being tested in speed trials. They have started from rest, have run through the official course, and have shown the ability to go to windward. The fastest speed so far recorded is less than 10 knots but they show improvement each year. Crossbow II handled the problem by reducing the rig centre of effort; improving sail control generally and running rigging particularly; optimizing board and rudder design over the design speed range; and improving crew-control system interaction including intercommunication. The sailing surfboard helmsman handled the problem by mainstrength, skill and perseverence.

The next generation of foiled vehicles is already appearing on the scene. Some are utilizing airfoils for both lifting and control (Figure 3). Some are using deep running T-foils for lifting and control. And a few are experimenting with combinations of aerodynamic and hydrodynamic lift and control systems. None of these vehicles has yet reached its design potential in speed trials. Every one of them is plagued by control system problems. Over a half kilometer course one crash or partial crash destroys a potentially good run because the permitted total times are of the order of 30 seconds only. [nf]^2 was conservatively designed to prevent crashing at the expense of unnecessary drag. She is no longer competitive because of this. The Stony Brook design team is presently in the midst of building a vehicle very much like that of Figure 1 with fully controllable deep running high speed foils. This idea will be tested next fall.

SUMMARY DISCUSSION OF CURRENT STATUS

The most interesting thing to the knowledgeable observer is not that Crossbow II exceeded a speed of 50 mph in a gust[2]. That may be surprising but it shouldn't be. It's literally predictable (Figure 5) proceeding from hydrodynamic first principles. Attainment of this speed is certainly a great tribute to the professional skills of the designer and the team that developed this vehicle. They did so by passing to the limit with well-established, existing concepts and technology and by working out the final development of the boat and sailing techniques on the water. Their success represents the culmination of a typical first class engineering effort. But it doesn't represent a breakthrough in sailing concepts. Similarly, the application of lifting hydrofoils to sailing vehicles is not a novel idea. A surprising thing is that foiled vehicles have not, in general, performed up to their expected potential. This state of affairs seems due partly to a degree of uncertainty in the drag prediction of the foiled sailing vehicle which has resulted in an overprediction of performance. It also reflects a design philosophy which seems to say "Let's apply hydrofoils to an existing sailboat" rather than "Let's design and develop a hydrofoil sailing vehicle." This latter approach is long overdue. Such a vehicle might look something like that shown in Figure 1. It would represent a design optimization with respect to tradeoffs on thrust, heeling moment, parasite drag, and stability and control. Especially needed is the development of a three dimensional control system.

Probably more interesting to the innovative designer than either of the above developments is the emergence and practical testing of the aerodynamic lifter as applied to the sailing vehicle (Figures 1, 2 and 3). If one thinks of this design as a hang glider spliced to a lightweight hull, it is easy to visualize short flights (possibly uncontrolled) out of the water in gusty conditions. In fact, according to observers of the world record run of the windsurfer, "microflights" were occurring during the run. Certainly, the kite men are capable today of producing sufficient lift to haul themselves off the water in moderate winds (Figure 2). However, none to date has succeeded in reducing his wetted surface element to the paravane shown on the sketch. This was accomplished in the early 1970's by Profrssor Jerzy Wolfe and his students at the Polish Aerodynamics Institute in Warsaw. According to Professor Wolfe, much crashing took place.

The most sophisticated flying boat to appear in the U.S. to date is the Amick "Wind-Powered Flying Boat".[1] This vehicle (Figure 3) is designed to take off under its own power and to glide back to the water surface. That the vehicle will sail and tack to windward and will take off under tow was demonstrated in December. Whether it will take off under windpower alone and glide in free flight remains to be seen.

One might summarize the state of affairs with respect to radical sailing vehicles design and development by noting that a lot of little amateur pots are boiling because there is no significant industrial support for this type of activity; at least not in this country. Any practical interest might be expected to come from the recreational vehicle industry; however, none has been shown to date to my knowledge. In the absence of such support, most of the developers are amateurs slowed by the necessity of pursuing the development of radical sailing vehicles as a hobby. The establishment of International Speed Trials with a money prize for an incentive has tended to focus the activity and to bring the world scattering of participants into contact with each other. Practical benefits to the boating industry from this far out group can be expected in the future.

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4. Bradfield, W. S. and Madhavan, Suresh, "Comparative Performance Soft versus Wing Rig," 3rd SNAME Chesapeake Sailing Yacht Symposium, January, 1977.

5. Bradfield, W. S. and Griswold, L. M., "Rig Polars from Wind Tunnel Data," 8th AIAA Symposium on Aero/Hydronautics of Sailing, March, 1977.

6. Bradfield, W. S., "Effects of Foil Control on Sailing Vehicle Performance," SNAME Chesapeake Sailing Yacht Symposium, January, 1974.

TABLE 1.

FASTEST OFFICIALLY TIMED SPEEDS UNDER SAIL (1978)

Type	Name	Gross Wt. lbs.	Sail Area $ft.^2$	Wind Force Beaufort	Boat Speed knots
biplane catamaran (displacement)	Crossbow II	4500	1200	Force 6	34.4
canard hydrofoil	[nf] 2	920	298	Force 4	24.4
canard hydrofoil	[nf] 2	720	218	Force 4	23.0
hydrofoiled catamaran	Mayfly	370	150	Force 6	23.0
sailing surfboard	Windglider	240	70	Force 6	19.1

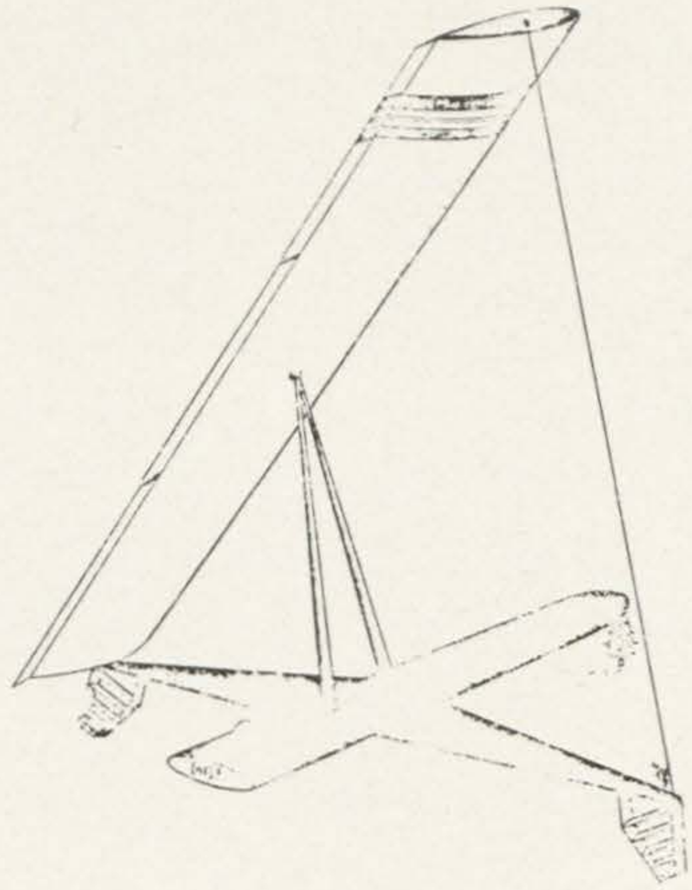


Figure 1. Radical Sailing Vehicle Design Concept

Figure 2. THE PARAVANE HANG GLIDER

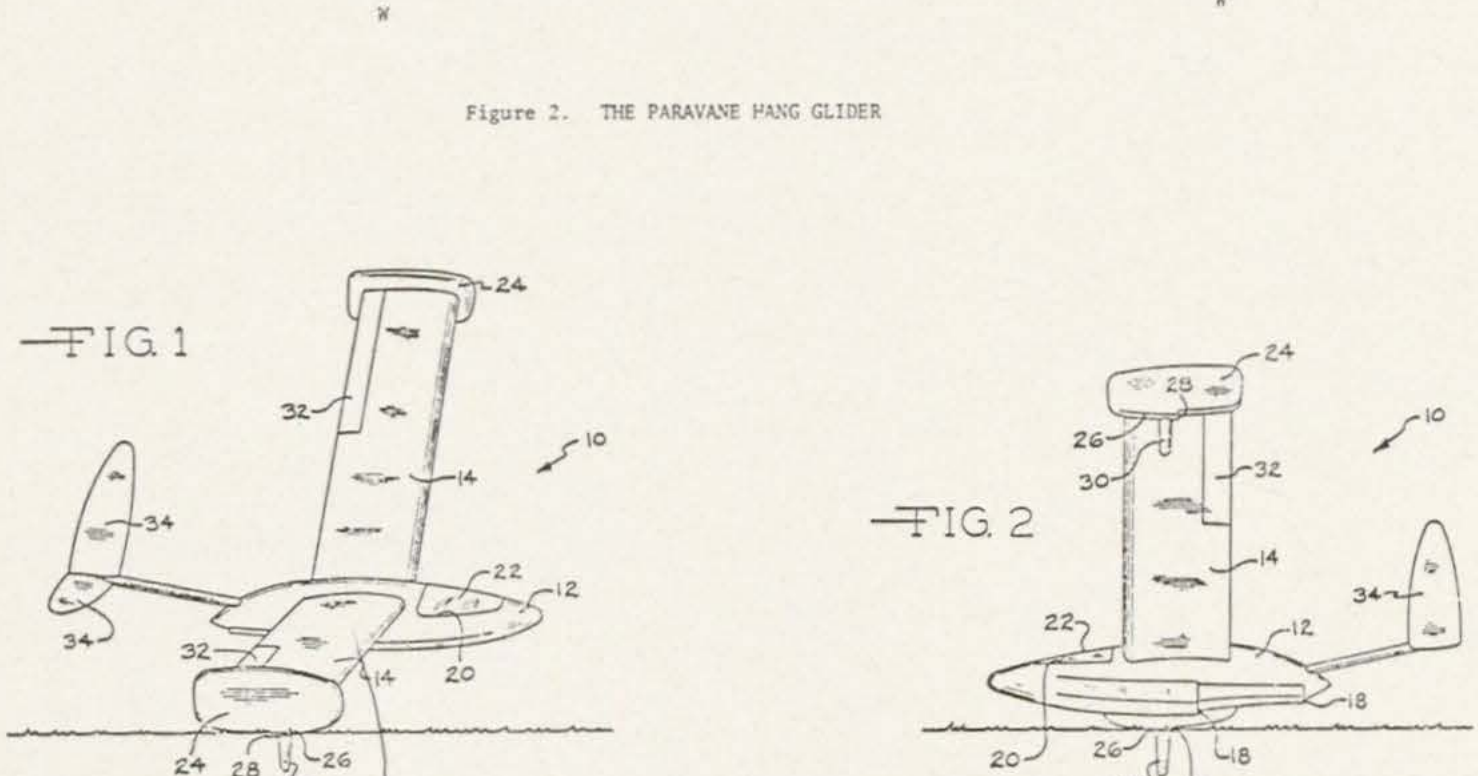
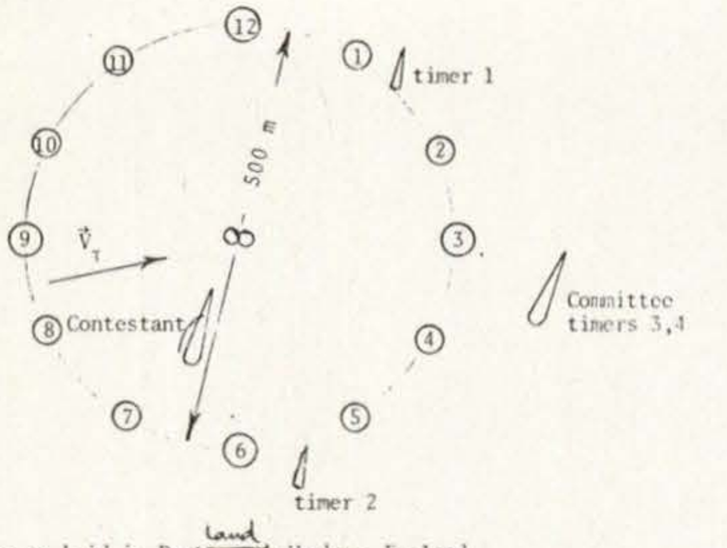
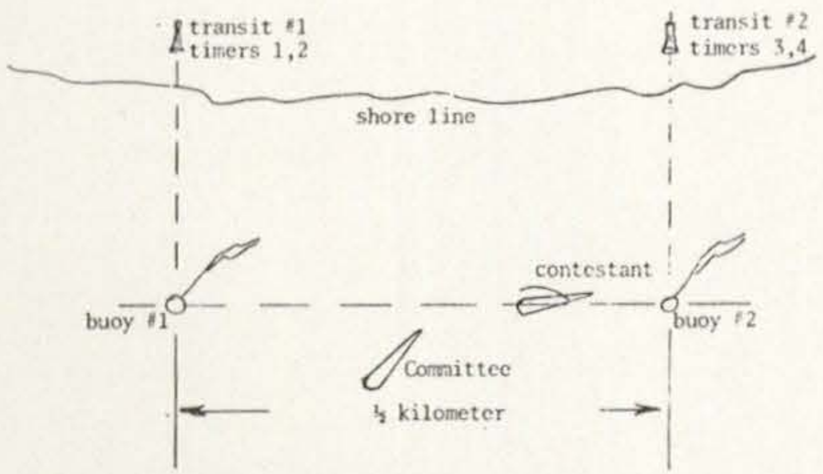


Figure 3. The Amick Wind Powered Flying Boat (sketches excerpted from U.S. Patent No. 3,987,982).



a) Official Course as Laid in Port[illegible] Harbor, England.



b) Official Course as Set in Port Jefferson Harbor, U.S.A.

Figure 4. Course Layout for Speed Trials Competition.

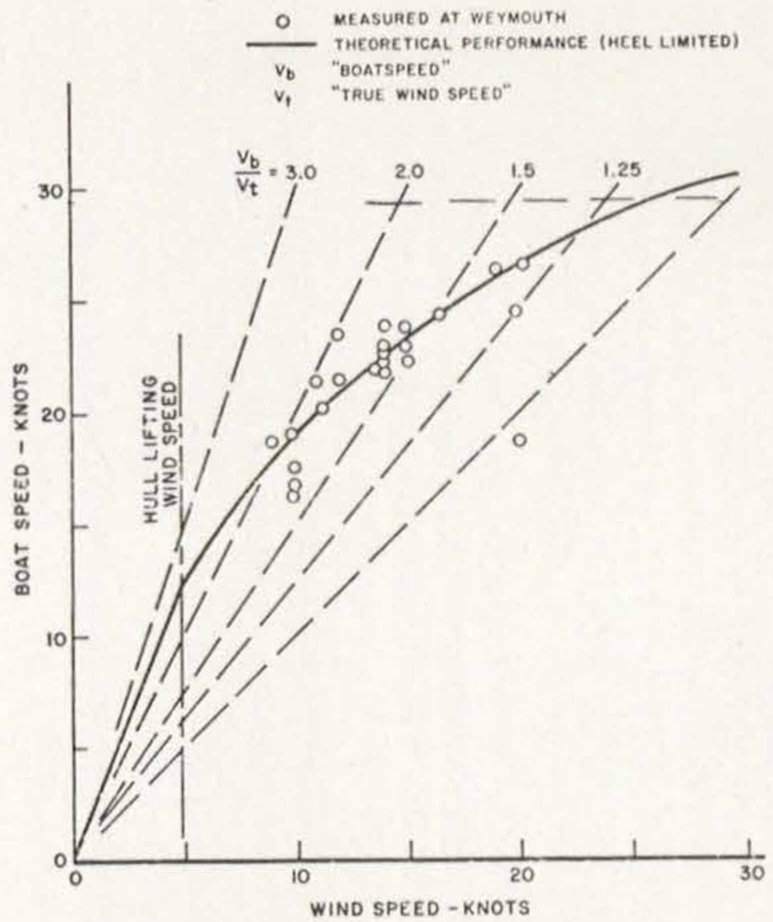


Figure 5. Predicted and Measured Performance of a Heel Stabilized Monohull.

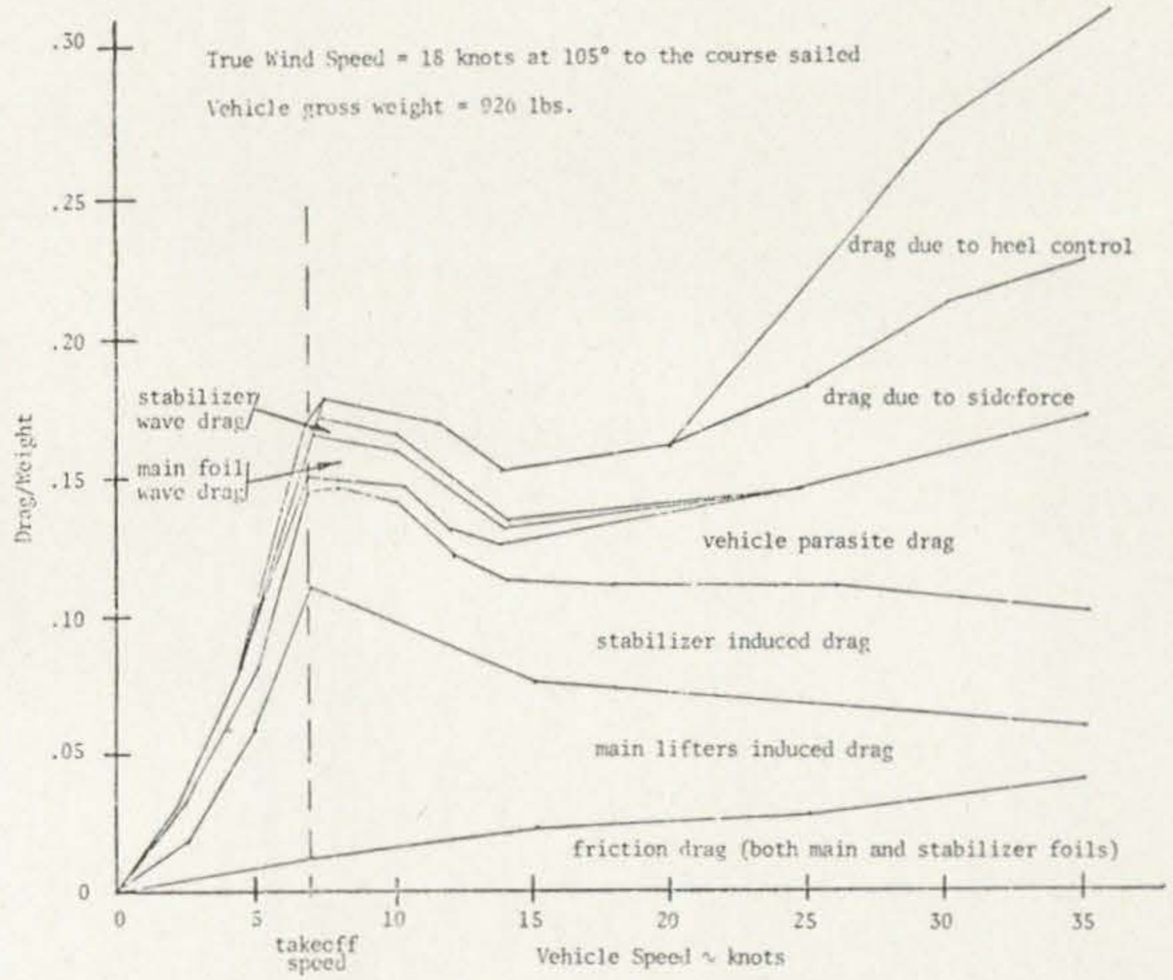


Figure 6. Drag Analysis of $[nf]^2$.

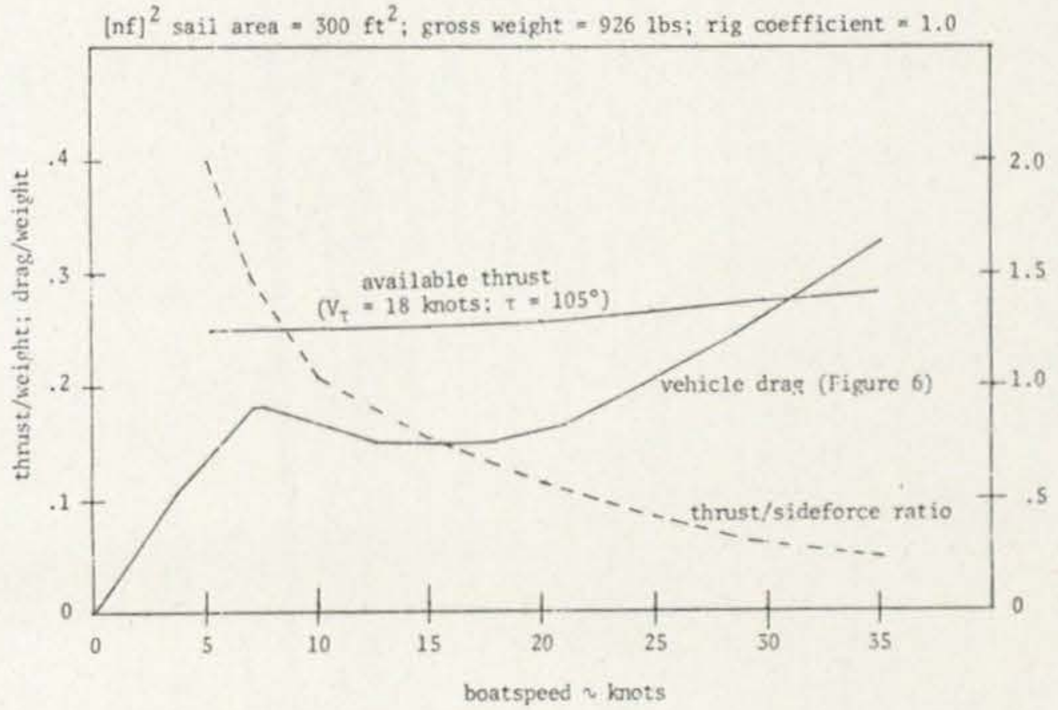


Figure 7. Performance Prediction for C-class Version of $[nf]^2$.

SAILING MEETING IN POOLE HARBOUR, AUGUST, 1978

By

K. R. May
Brook House, Middle Street, Salisbury, Wilts.

In a summer which had been pestilential, we were fortunate that the 1978 meeting coincided with the start of a long spell of good weather. Too good for us perhaps in that the very gentle breezes ruled out serious sailing and it was not until Sunday evening when all visitors had departed that there was a fair weight in the wind.

The meeting had been brought forward for an extra day, Friday, with the intention of holding an organised race with prizes to test some of the new "Ayrsfoil" boats against comparable others. In the event, no one had had time to put together any of the former and only four of the latter, "Bluey"? "Tritor," "Kelek" and "Kiki" were present. There would have been five but Alex Roeves, who had been making some remarkable long coastwise voyages in a 16 foot "Mirror" dinghy equipped with stabilising foils (of which he speaks with some enthusiasm) had come to grief at Eastbourne on his way to Poole. While anchored overnight rocks had pounded the bottom and the hull had to be written off.

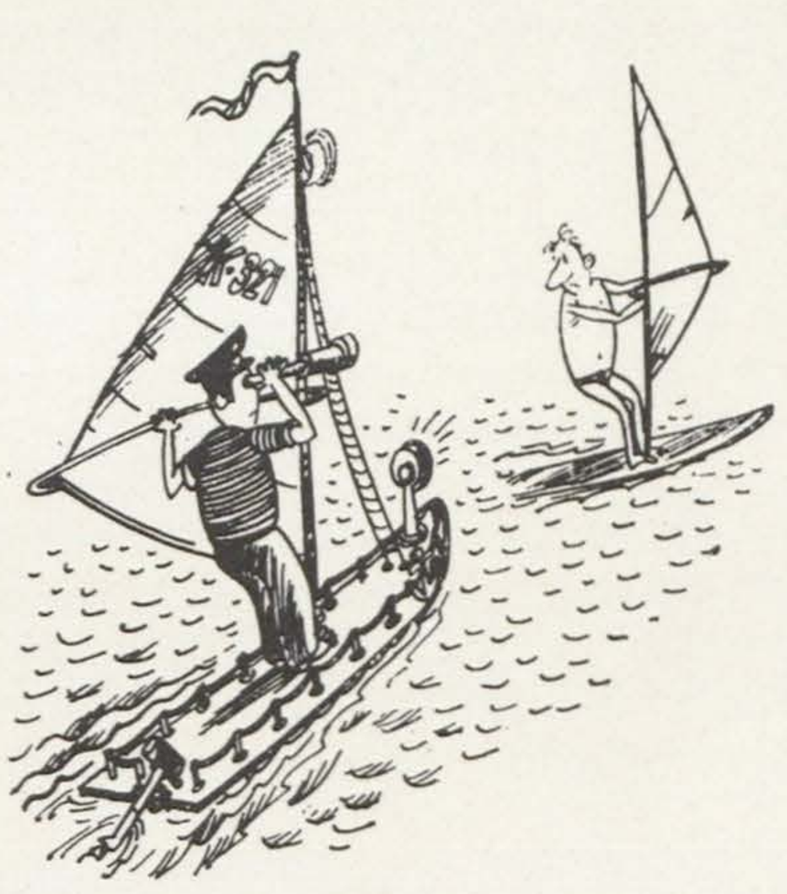
Apart from the above four, a new and welcome visitor was Roy Butler with his Telstar "Krystal" and Mike Ellison came in Reg White's new 32 foot cruising cat "Comanche" in which they had just done so well in the Observer Round Britain Race. Many members and friends inspected the luxury of this boat with some awe and it did some useful hotel work during the meeting.

If boats were few, members happily were not. Many made brief or long visits such as M. Sutton-Pratt, S. Coleman-Malden and E. Morton-Davis to name but six. G. Turberville-Smith with his "Cracksman" cat was among one or two others who for various reasons were unable to bring their cruising boats. However, we did have some very interesting models all of which sailed. Of these models, our radio control expert David Boothroyd brought two from Leeds. One was a conventional Marblehead sloop with sheet and rudder control from a small hand held console. When operating this, one at once realises how fascinating and skilful racing these highly developed craft must be, also what an ideal system it is for testing experimental rigs at relatively low cost. David's other boat was a remarkable experimental catamaran with a rig which tilted in gusts and at the same time brought Bruce foils down into action. On one occasion the craft went beyond radio range and proceeded merrily down the harbour until rescued by young Chapman in his canoe.

I produced a 3 foot trimaran rigged with an attempt at a practical version of John Morwood's semi-elliptical sail. There is a backward sloping unstayed mast and the sail battens are shaped to bend to circular arcs with a flow of 1 in 8 when their bowstrings are taut. These bow-strings run across the mast so that when the sheet from the bottom lee corner is hauled back to a circular track, the centre of effort of most of the sail is astern of the mast. To tack the sheet is released and the sail pushed forward into the eye of the wind, whereupon the sail flicks round quickly but quite safely to the other side of the mast and the new sheet is hauled in. This works fine in the model but whether it would be a practical system on a small yacht is obviously moot until tried by some stalwart. The secret of the rig is a spring loaded "kicking strap" connected to points near each end of the bottom batten and which runs through a slider on a rotating boss round the mast at the deck. This keeps the whole sail rigid all the time. The sail reefs down nicely to each batten and seemed to develop plenty of power, under self-steering control.

Bob Smart's model must be just about the most way-out ever seen. A long and extremely narrow central hull had a large "squashed-sphere" crew capsule at its centre point and from this small sponson arms sprouted to give lateral stability. On top of the crew capsule a relatively tiny single 'Planesail' of the Fin Utne or John Walker type was mounted. The craft is symmetrical so that it sails equally well either way. In spite of the tiny sail, it went very well in the force 1 prevailing when it was tested. Bob intends to build a full sized prototype in the South of France and if it is successful the craft can not fail to be a sensation.

Рис. В. Боковни



The four small boats mentioned earlier were all kept busy taking out members and also had a couple of impromptu races in lieu of the more serious one which was planned. The first on Friday was of about 4½ miles round Furzey and Green Islands and the second of about three miles in less restricted water. Both were comfortably won by George Chapman in his 16 foot 10 sq. m. wingsail catamaran "Bluey." Starts were push-starts in line a-beam from the beach and Georges crafty last minute moves before the off to ensure that he had the far windward end of the line didn't matter because he would have won anyway! "Bluey" sported the latest version of the line of Chapman wingsails and very perfect and beautiful it looked. The high efficiency of the sail was clearly shown by the boat speed in light airs and its remarkable close windedness, in spite of the lack of centreboards. With two up in the second race she seemed to go even better than single-handed in the first. "Kelek" which came second had her 12 sq. m. sloop rig up and is no sluggard but was comfortably outsailed on all points. She only nosed ahead briefly on a beat up a narrow channel due to her quicker

Poole Rally 1978
Above: Ken May and Midge on "Kite".
Top Left: George Chapman's "Bluey".
Left: Bob Smart's boat.
Bottom Left: "Comanche".

Assembling TRITOR
R to L. E. Morton, Davies, Alex Roeves, Betty May, David Jolly, Ralph Farrant, Bob Smart, Peter Ryalls.
In background – KRYSTAL, KIKI, KELEK.

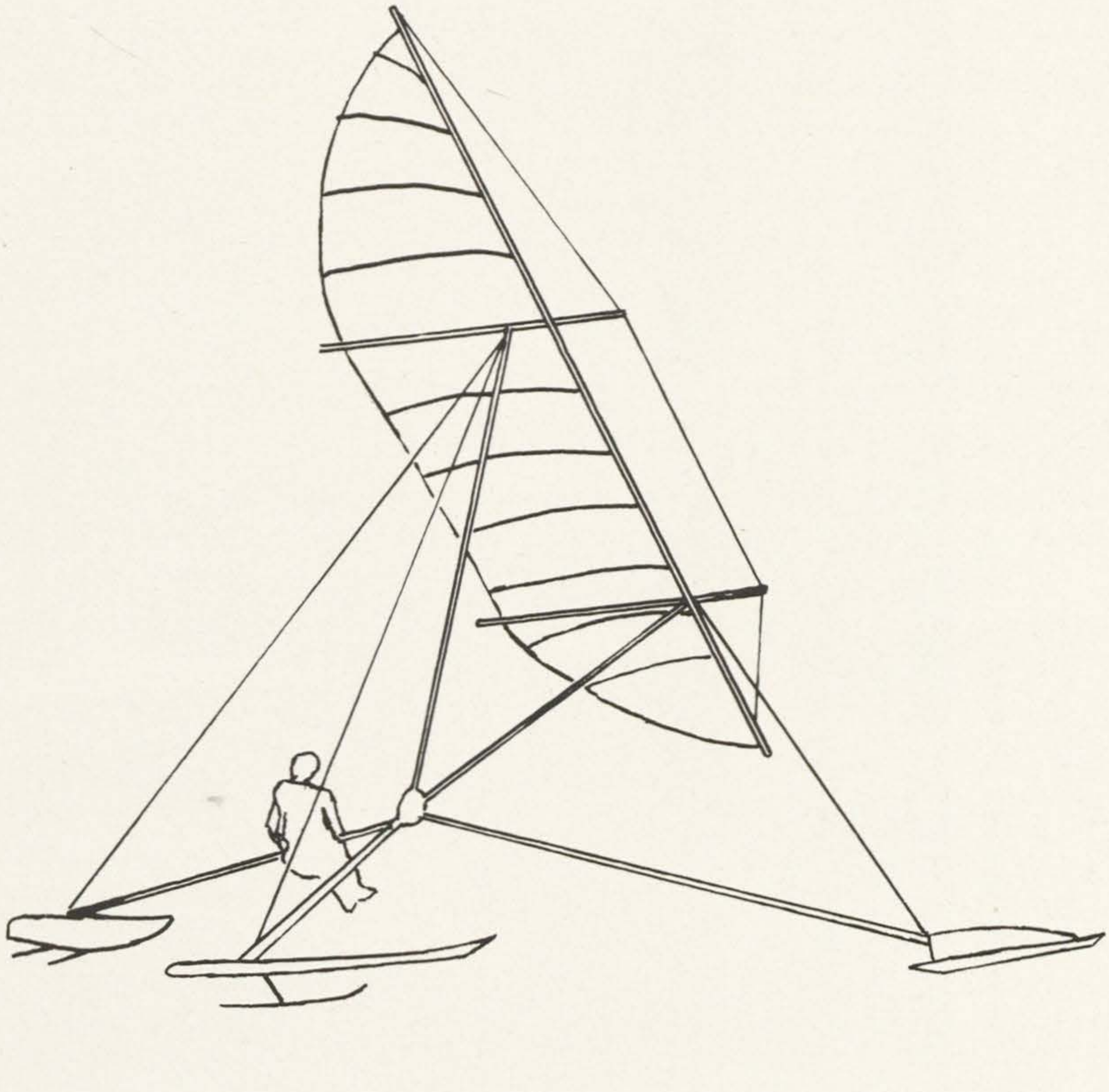
tacking and a wind shift. When sailing "Bluey" one cannot fail to be impressed by the rig's docility and power. Let it weathercock and the boat just sits still in uncanny silence. Sheet in and she's off with immediate acceleration. Nor does the angle of attack seem critical. To tack, the boat is brought into the wind, the foot of the sail pushed by hand to flick the opposite camber, a quick reversal of the helm in the ensuing stearnboard and she's off. One feels that the rig is rather heavier than conventional ones, it may be unwise to fly a hull and its ability to withstand strong winds needs to be demonstrated. As a trimaran fan, I feel it would be wonderful as a free-standing mast in a tri.

To return to the races, "Tritor" which was 3rd in the first race and 4th in the last is a very handsome new assembly by Eric Morton-Davis, having her first proper outing. A tornado cat main hull has two g.r.p. outriggers from a small commercial cat giving a beam of 12 feet. A full width trampolene gives a lot of 'deck' space and she has a sloop rig of about 14 sq. m. Certain deficiencies in strength of crossbeam attachments etc., showed up during the weekend and when these are put right and when more good sailing time is put in, Eric should have a fine craft, seaworthy and fast.

"Kiki" had been designed for the Portland speed trials with no thought for manoeuverability or upwind ability, so she naturally showed at her very worst in the round-the-bouys racing in light winds. I hope my general observations on her will be of interest. She is shown on page 37 of AYRS 90 in her 'Pacific' proa form but she is now a tri. with 12 ft. beam and two very narrow Vee floats like the single proa one. A wishbone replaces the diagonal single spar 'hard and soft' tack arrangements used for the 1977 speed trials. Thus we have a seaworthy trimaran equally at home on either tack, instead of the proa which is a pretty dangerous and useless type of craft for most purposes. In light winds the proa form was very slippery whereas in similar conditions perhaps because of the increased weight and drag, the tri is sluggish and "Kelek" has then literally sailed rings round her. Of course "Kiki" with long narrow hulls has high wetted area and is much under-canvassed in light winds but as the wind pipes up her lack of wave-making and her una rig come into play and the performance is transformed. She has a lovely motion in the open sea and with two up (giving a Bruce number of only 1.3) we have had the indecently enjoyable experience of twice overtaking dense fleets of yachts varying from small racing dinghies and keelboats to a modern 50 foot cruiser which seemed almost to be standing still.. Very satisfactory! It may be that the trimaran form is ultimately faster than the Pacific proa because the stability enables it to be driven harder, but this remains to be seen.

It has been said in A.Y.R.S. publications that low aspect ratio foils or boards are inefficient for upwind work. I was aware of this in building "Kiki" but for the speed trials close windward ability is of little consequence so she has no centreboard and relies on the long hull and narrow floats for lateral resistance when reaching. If you try to push her sideways when at anchor the resistance is enormous, but sure enough she does make a lot of leeway when hard on the wind, to give a fairly wretched V.M.G. and she is murder to tack. As an experiment, I fitted "Kiki's" mast and sail to "Kelek" which relies solely on the centreboard for lateral resistance and which unlike "Kiki" is rapidly manoeuverable. Leeway was now good and the boat delightful to sail but unfortunately the wind was again only around force two and tagging on to some Wayfarers on a beat I could do no better than keep level with them, rather humiliating. "Kelek" with her 12 sq. m. sloop rig can beat them and in a good breeze, leaves them standing. It was noticeable too that the 10 sq. m. una rig with its higher c of e gave a good deal more heel than the 12 sq. m. sloop rig. So I conclude from all this that in light winds a sloop rig is much better and more versatile than a una rig and that a high aspect ratio centreboard is the thing for good V.M.G., unless perhaps you are lucky enough to have a superior sail with high lift/drag like "Bluey's."

Members were generous in bringing food and drink to the meeting and may a fine spread was prepared by Betty May with welcome assistance from other good ladies.



Sketch of Entrant in speed trial at Heretaunga Y.C., N.Z. sent by M. N. Foggo

ENTRANTS IN THE 1978 SMIRNOFF SPEED SAILING WEEK

Held at Weymouth, 7th – 14th October, 1978

Compiled, and with comments by, Cdr. G. C. Chapman, R.N.

Notes:

1. **The data for each boat is presented thus:–**

Entry Number / Boat Name / Owner/Helmsman / Boat Speed (Knots)
Date / Wind Speed (Knots) (where known).

2. Entrants are shown in the Class in which they performed, although they may have initially entered in another Class. No. 31, KITE-YACHT I is listed under Class A, although originally entered under 10 sq. m.: this boat could also have sailed in Class C, in fact made no timed runs.

OPEN CLASS

26 SLINGSHOT
Karl Thomas
21.6/7 Oct./14

60 ft. trimaran: small pods on two cross beams which slide to and fro across main hull, so that boat is sailed with windward pod on extended beams, i.e. as a Pacific proa. 650 sq. ft. sail in main and yankee jib. Main hull: 850 lb., pods, 105 lb., total boat weight: 1850 lb. Designed: George Thomas, built Mead Gougeon, Michigan, U.S.A.

40 CROSSBOW
Tim Coleman
27.7/7 Oct./15

Catamaran, 61 ft. hulls, staggered by 13 ft.– port hull leads. Boat weight 4000 lb. 1300 sq. ft. in two equal sails, booms inclined from centre of masts to clews. New sails this year, and improved planing show on starboard, windward hull. Hulls strengthened after last years overstress which produced 8 inch hole in starboard side of port hull. (Winner of the Open Class Prize).

43 CRUSADER SEA WOLF
John Perry
No runs

51 ft. ocean-going catamaran, designed and built by John Perry. Handsome arched beams contain parts of the accommodation – but failed to pass scrutineers for the 1978 Round Britain Race.

44 TRIMAMA
Roland Tiercelin
9.7/9 Oct./12

40 ft. trimaran, 3 masts with wishbone booms. Small inward-angled centre-boards on each float. Derived from Tiercelin's earlier Cheri-Bi-Bi.

CLASS C

1 SMOOTHY
John Vigurs
10.3/8)ct./

"C" Class Catamaran. New hulls of g.r.p.-covered aluminium honeycomb, reinforced with carbon. Suffered structural failures – back to the resin-pot.

41 GEL AR MOR
Messieurs Rivou,
Cunin, Quistinic, Corbel.
(Les Crocodiles de L'Elom) (!)
10.5/10 Oct./14

4 sail sailboard, 14 metres long. Winner of the C Class Prize.

8 JACOB'S LADDER
Ian Day
7.6/10 Oct./12

12 ft. catamaran with ladder of rectangular FLEXIKITES.

(27) BLUEY
George Chapman/
Maggie Chapman
10.9/10 Oct./11

An entirely unofficial entry, allowed to run under BANDERSNATCH's Number, after the latter had retired, and BLUEY had come as a spectator boat. This non-entry is recorded in order to encourage entries in C Class! BLUEY was sailing with two up, displacement, and about 127 sq. ft. of very conventional sail.

B CLASS

2 ICARUS
James and Andrew
Grogono
19.5/7 Oct./15

The original ICARUS, with foils that are now 5 or 6 years old. New rig this year, still standard Tornado. Offered for sale at £1000. Winner of the B Class Prize, and the "Portland" Challenge Trophy for the boat doing proportionately best in its class in relation to the existing record.

5 HOBIE 16
Coast Catamaran Ltd./
Nigel Gent
14.3/7 Oct./15

Standard 16 ft. Hobie Cat.

6 FLYER
John Walker

Did not appear – for the second year running.

9 UP FROM THE SKIES
Simon Sanderson
No runs

Canard Hydrofoil, similar to GUIDED MISSILE and TEN CATE SPECIAL. Long narrow hull: small double inverted T/rudder forward, large surface piercing V foils under high crossbeam aft. Tornado mainsail.

10 FOILER 21
Robin Webb
14.6/7 Oct./15

Standard 21 ft. production model, based loosely on Gerald Holtom's Foilers.

23 ORLANDO 2
Grant Ward
No Runs.

Trimaran with small side floats, surface piercing V foils on forward cross beams.

33 HI-TROT III
Kanizawa University/
Toshio Namamura
5.5/7 Oct./10

Wide catamaran with bi-plane wingsail rig. Mast on each hull, aeroplane configuration surface piercing foils. 16 sq. m. total sail area.

48 NACRA 5.2
Tony Oeuvren
14.4/9 Oct./15

Standard Production Catamaran.

45 EXOPLANE 2
Didier Costes
6.5/8 Oct./

Hydrofoil proa with inclined sail. A most ingenius concept, which has shown flashes of speed, but for want of proper engineering has never lived up to its full potential.

A CLASS

3 HOBIE 14
Coast Catamaran Ltd./
Brian Neve
12.3/7 Oct./

Standard 14 ft. Hobie Cat.

22 SWEENEY
Mike Todd and
Bob Purnell
9.0/10 Oct./12

Tandem free-sailing Atlantic proa hydrofoil. Surface piercing foils under main hull, small inverted T under leeward float. Boat weight about 250 lb., plus 350 lb. crew.

24 FORCE 8
Doug Pattison
12.8/8 Oct./14

Trimaran, small side floats, single crossbeam. Three inverted T foils, forward ones with incidence controlled by feelers and the pilot. Wingsail, NACA 0015, with flap on upper 2/3. Winner of the DESIGN PRIZE.

25 MAYFLY
Ben Wynne
18.7/9 Oct./15

The original hulls, Newcastle University surface piercing foils, this year with a new streamlined trampoline, and projecting side trampolines in lieu of trapeze. Boat weight 250 lb. Winner of the A Class Prize.

28 SUPER NOVA
Ole Kaj Thorrud
11.1/10 Oct./12

13 ft. trimaran, G.R.P., very neatly moulded. Floats on the small side.

30 RAMPAGE
Mark Simonds
8.7/9 Oct./12

Unicorn with foils. Inverted T under port hull has flap controlled by feeler, pivotted at bow and lying aft. Fixed inverted T in starboard centreboard case. Inverted T rudder on port stern – i.e. three point support of the whole boat. Standard Unicorn rig.

31 KITE-YACHT I
Keith Stewart
No runs

25 ft. narrow hull (similar racing pair oar), large leeboard, moveable crossbeam with small pod, propelled by one of a choice of delta-wing kites, either 120 sq. ft. (A Class) or 300 sq. ft. (C Class).

32 4th IMPROMPTU
Bill Hatch

Did not appear.

36 SEAFLY A
Terry Crumpton
14.7/8 Oct./15

16 ft. production prototype hydrofoil catamaran, derived from the original MAYFLY much as she was in 1972-76. Hulls now GRP/Foam sandwich. Foils of welded aluminium, with short vertical elements on the main foils to improve yaw stability.

10 SQ. METRE CLASS

4 HOBIE 14
Coast Catamaran Ltd./
Max Townsend
12.5/7 Oct./

Standard Hobie 14 Cat., but with 10 sq. m. sail.

7 HANGSAIL
BARRACUDA
SPECIAL
Clive Colenso
11.8/10 Oct./12

Sailboard.

11 DICE
Jon Montgomery
12.1/7 Oct./

Inflatable catamaran. Longer floats than last year's SISI, but the aluminium frame was if anything a bit too lightly built.

12 MANTIS
Mike Ellison/
David Chinnery
No runs

AYRS-Foil hull, unstayed mast, luff pocket sail, wishbone boom, stabilising foils on large crossbeam.

13 AUSTER
Reg Bratt/Mark Cady
11.8/10 Oct./

20 ft. catamaran, wingmast wishbone rig, small surface piercing foils forward, inverted T rudders. Reg points out that the boat weight is 270 lb.

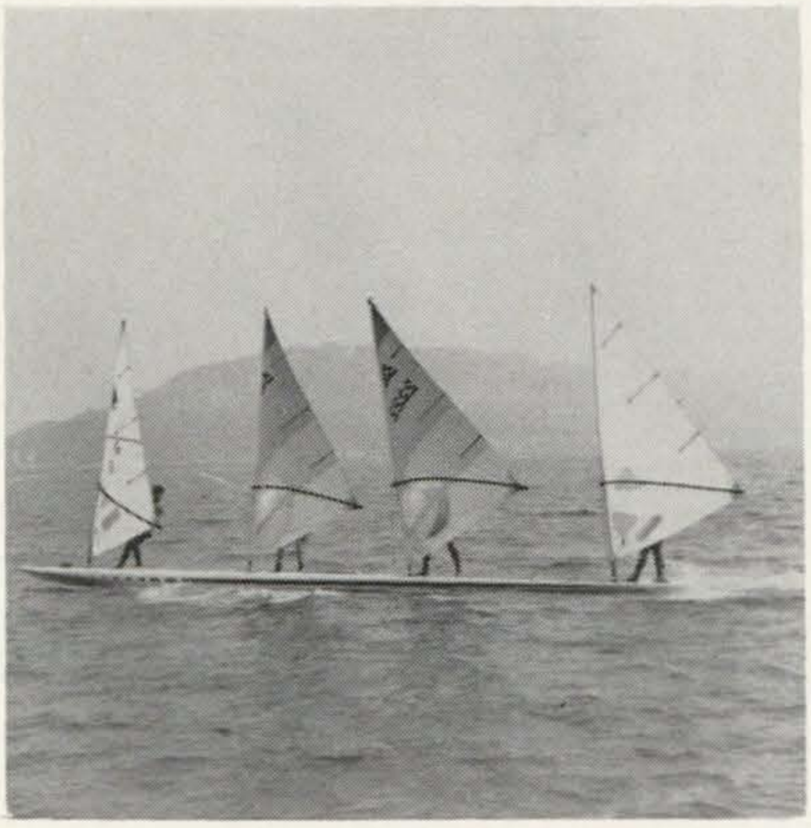
Michael Ellison on left with Measurer/sail maker, Clarence Farrar on right (AYRS Vice-President). Photo by Jack Heming of Multi-Hulls International.

Philip Hansford on right, looking at "New Mayfly of his design, but now developed by Newcastle University.

10 SQ. METRE CLASS Continued

14 TC 39 SPECIAL Gary Seaman/ Jaap Keller/ Jaap Rest 13.5/10 Oct./13	Sailboard.
15 TC KAJAK SURFER Gary Seaman 8.8/8 Oct./	Sailboard
16 TC SPEED SKI Jaap Rest/Jaap Keller 13.9/10 Oct. 14	Sailboard.
17 TARKA 2 "S" Sedgwick Stephens Ltd. 10.1/8 Oct./	Small production catamaran.
18 ROTA HIASL Bernard Schistek 8.1/9 Oct./	Sailboard.
19 BIPLANE George Randall No runs.	20 ft. catamaran; single deep bridge structure well aft, narrow triangular section floats, tapering forward, A-frame rig.

20 NODROG Ken/Gordon Way 10.0/10 Oct./	Sailboard, luff pocket of sail filled with foam to make it a wingsail.
21 WAYBO Ken/Gordon Way 8.9/10 Oct./	Sailboard.
27 BANDERSNATCH George Chapman Dismasted	14 ft. catamaran, Mk. 3 wingsail. Inverted T main foils mounted below surface piercing V's, the whole controlled for incidence by feeler foils right forward. Inverted T rudder. Mast fell down during first timed run on 8th October due to inadequate shroud plate fixing.
29 BLACKSMITH Fraser Black/Andrew Smith 11.1/8 Oct./	Tandem Sailboard.
34 FOAMER P. J. Bromley	Sailboard. Broke with tradition by not appearing – despite flat calm on the last THREE Days.
35 KIKI Ken May/Jonan May 12.8/7 Oct./	Triamaran, based on cut-down Tornado hull, with wishbone-boom rig. Also appeared as a proa by discarding one float.
37 SEAFLY (10 sq. m.) Harry Harrison 15.7/10 Oct./14	See SEAFLY A in A Class – this boat had a 10 sq. m. sail.
38 WINDGLIDER RANGER Derk Thijs 15.6/10 Oct./14	Sailboard.
39 NAVIPLANE Roger Durand 5.0/13 Oct./	Sailboard.
42 WINDJAMMER Clive Lewis 11.0/10 Oct./	Sailboard.
46 WINDSURFER SLED Matt Schweitzer 12.7/9 Oct./	Sailboard – Standard TC 39 by Ten Cate Sports BV.
49 NAVIPLANE Jean-Yves Durand No runs.	Sailboard.

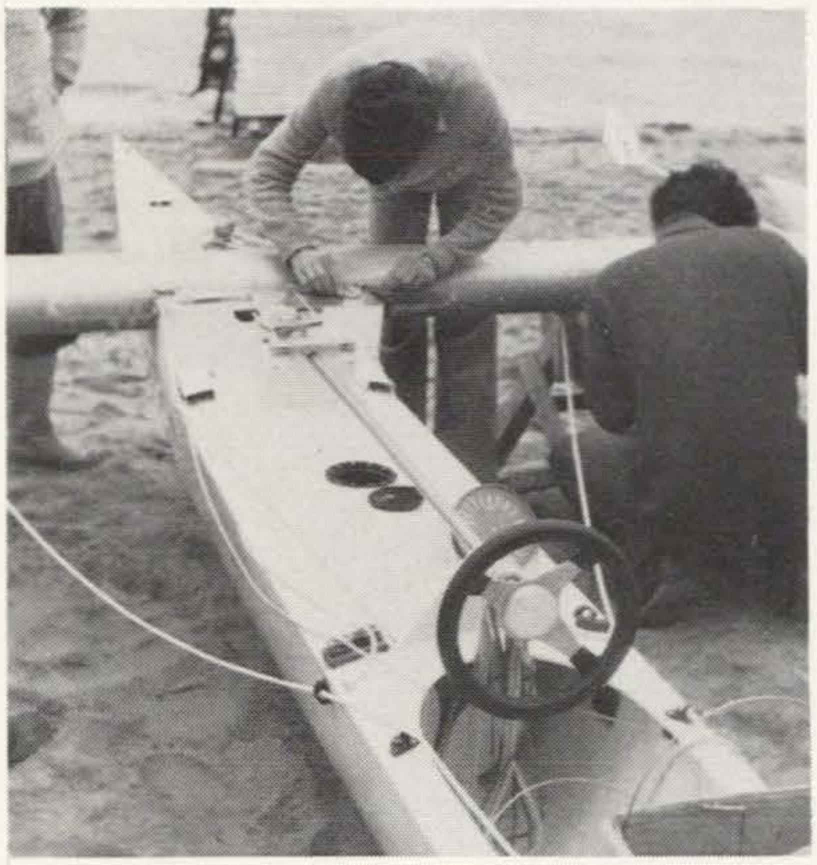


Two, three and four person sail-boards have so far been slower than single boards. The opposite to the case with rowing or bicycling.

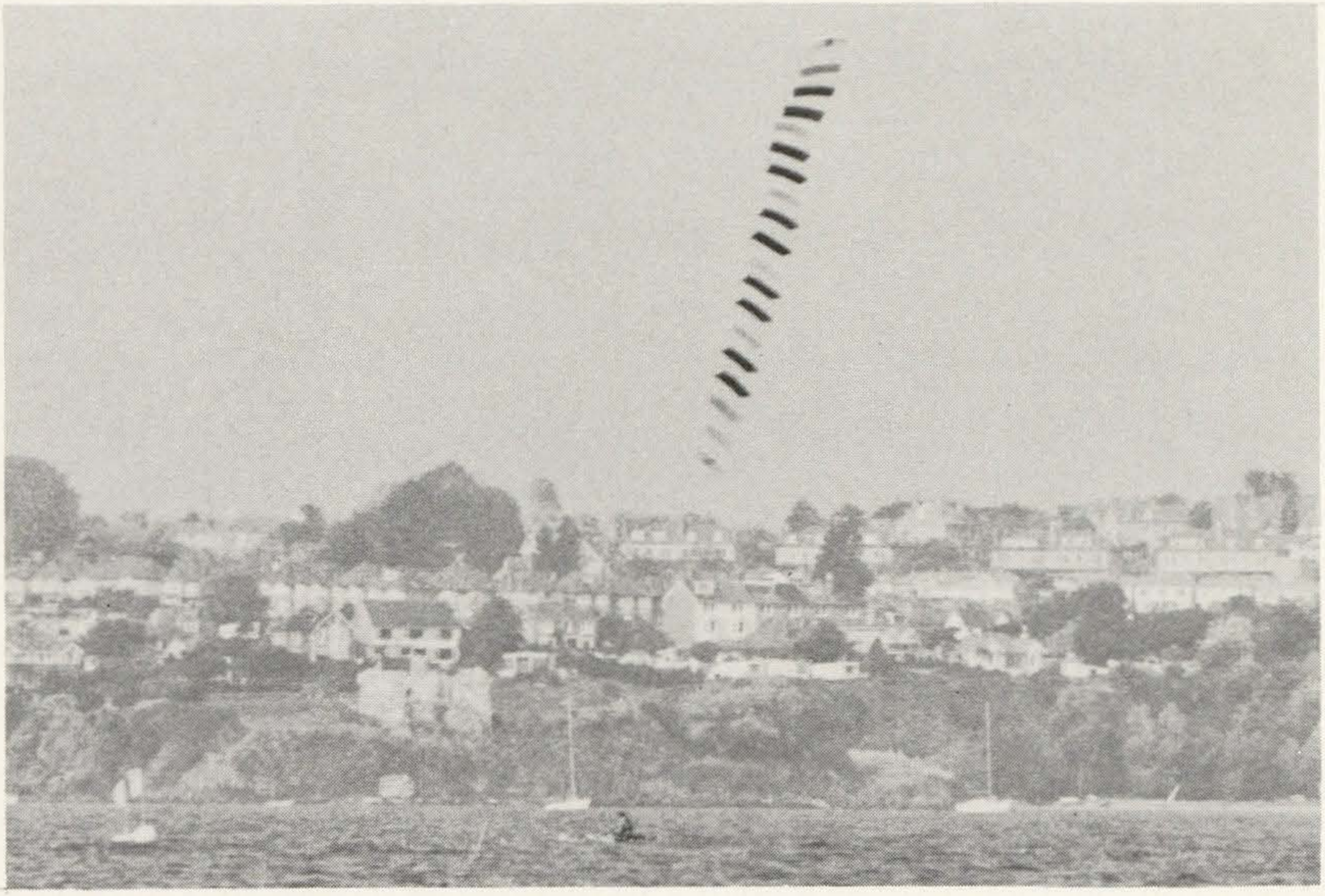
Exoplane 2. Angled sail and hydro-foil to leeward. She has sailed fast but never across the measured course!

FORCE 8 – D. R. Pattison

This interesting craft won the design prize at the 1978 Portland Speed Trials. Basically the same as previous years but improvements to details enabled her to 'fly' for reasonable distances even in the modest winds available during the week. Steering is by foot pedals – the wheel turns to alter the angle of attack on port or starboard foils to counteract heel and the wheel is moved fore and aft to control both foils together. Foils are also linked to the surface feelers.



Force 8



"Jacob's Ladder" was one of two kite propelled craft. The number of kites flown varied, there are 19 in these snaps. The kites are 'flown' in a figure of '8' pattern to gain extra wind speed and drive but are kept at a constant angle for 'kiting' to windward. The number of kites can be varied to suit the wind strength but if the kites fall into the sea they cannot be 'launched' (?) when wet. The two control lines are wound onto the drum.

Letter from P. M. Lawrence, 64 Marlborough Crescent, Riverhead, Kent.

Dear Mr. Ellison, 27th January, 1979

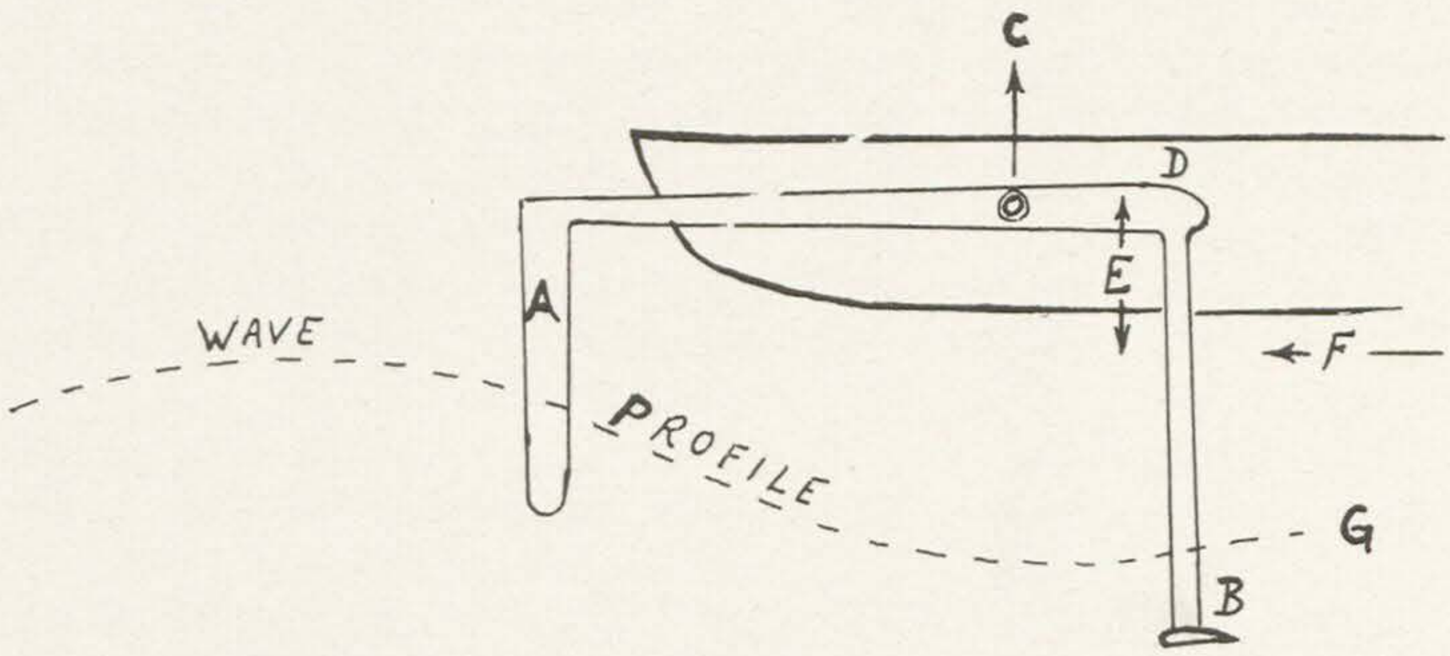
I have been thinking about the problems of making a fully practical lifting hydrofoil system, and trying to reconcile the practical limitations of how complicated a foil system should be allowed to be with making the system perform as I would like. I think I have discovered such a system, at least in theory, so I am putting it out for other members to think about.

Basically, I decided that a surface-piercing foil system could not be good enough for all conditions, as leading and following waves both have the same surface profiles, but with diametrically opposite movements underneath (orbital motions). These orbital motions express themselves at the foils as changes of incidence, and the effect can easily be overcome in incidence-control systems by anticipating the incidence change and correcting for it as it occurs. The only difficulty is, that you are at once in the field of moving parts, and continually moving parts at that. To get round this, I decided to see what I could do with only one moving part (to allow incidence change), and that mounted on a large bearing above the water-line. That immediately narrows us down to some sort of bogie arrangement like that shown, but leaves us with the question of what combination of foils and skis to put on it, what proportions and areas, what built-in incidences and what masses. After all, it is only things like that, that make the difference between a dead tree and the Cutty Sark!

In making these choices, I have used two different theoretical principles. I am not going into the mathematics of it as anyone who could understand it can probably work it out for himself.

First principle: Other things being equal, the lift on a foil is roughly proportional to its incidence (within certain limits), and therefore the lift on a foil with high built-in incidence is less sensitive to orbital motions than one with low built-in incidence, because the incidence changes are a smaller proportion of the whole. Why not just use surface-piercing foils with high built-in incidence? Because there would be too much drag to go foilborne, and also there would be a risk of stall. This sensitivity is already used to avoid crash dives by making the forward of a pair of surface-piercing foils with more built-in incidence, so orbital motion moves the stern more. If it were the other way about, the bows might be pulled sharply down which would add to the loss of incidence already produced by downward orbital motion, eventually leading to negative incidence and a crash dive (upward orbital motion is not so critical; but any wave has as many downs as ups).

The built-in incidences actually used on surface-piercing foils work the other way, countering the incidence changes of orbital motion by tilting the whole hull the other way. Well then, why isn't that good enough, and contrariwise, where is the improvement in my bogie? Well, countering incidence is not the same thing as anticipating them, so some of the vertical accelerations produced by the orbital motions still get rhrough. Also, "tilting the whole hull" is known in the trade as "pitching," with perhaps some roll and yaw thrown in, so we would only be exchanging one evil for another. Admittedly, there might be some one point which is instantaneously at rest, but we are talking about a whole boat. Or are we? I will come back to that later. This pitching could not communicate to a boat through a bogie bearing, and we can afford to let a bogie pitch more than a hull as it is lighter and smaller than a hull and does not directly carry rig, payload or crew; so we are better off to that extent. But what about the left over vertical accelerations? This leads us conveniently on to the second principle I mentioned.



A Forward surface piercing foil with high built-in incidence and small area.

B Amidships, fully submerged foil with small built-in incidence and large area.

C & D Bearing and lines of action of average lift and drag.

E Line of action of changes in lift due to 'G'; this is aft of 'C'.

F Motion of hull.

G Orbital motion of wave; this causes changes of incidence at 'A' & 'B', hence forces at 'E'.

Second Principle: The Centre of Percussion. This is where the mathematics would go, if I were going to put them in. It is not especially to do with boats, but it fits here and you may remember it from school the way I did. It states that for any object, if you hit it no matter how hard on any line NOT PASSING THROUGH THE CENTRE OF GRAVITY, then there is some point (the centre of percussion) about which the object will instantaneously pivot. The centre of percussion is determined solely by the line force and the distribution of mass in the object; there are no technical difficulties to the measurements and calculations involved. If the object, as it might be my bogie, has its bearing at the centre of percussion for a line of force corresponding to E in the diagram, then vertical accelerations would not be transmitted to the hull as, for all its pitching, the bogie would not be trying to move the bearing. On the other hand, if the average force is centred on the bearing, the hull is held up; we can arrange for the line of force variations to be different from the line of average force by giving foils A and B different sensitivities as shown. These lines are entirely fixed by the built-in incidences, so we should get the following effect: although the bogies as a whole does not anticipate orbital motion, its bearing does and that is all that matters.

That is the basic hydrofoil bogie. In practice, it won't work quite perfectly, but it should be worth it; it's even retractable by rolling it back on itself. There are some questions I have not discussed, such as the relation of foil sensitivity to dihedral as well as built-in incidence, and to what extent this makes incidence control sensitive to leeway; these actually would need mathematics, so suffice to say that they can all be brought under control. It is worth mentioning that we can fit a hull with bogies on each side just forward of amidships, provide them with the right dihedrals to be insensitive to leeway and function as Bruce foils to prevent heeling, and replace the rudder with a high built-in incidence surface-piercing foil which would be insensitive to orbital motion, would not permit a crash dive as the bogies would be even less sensitive, and would have low drag as most of the weight would be on the bogies. Bogies, by the bye, have low drag because most of their load is on the submerged foils which have low built-in incidence.

There is really only one thing left, and that is to ask people to see if they can work out a way to help the bogies get foilborne as I think there might be problems in that area. It would be quite a blow if this system was only useful on power boats!

Yours sincerely, P. M. Lawrence

Letter from W. R. Frank, 87 Staincross Common, Mapplewell, Barnsley, Yorkshire S75 6NA, England. 22nd December, 1978.

To Noel Fuller, 7 John Davis Road, Auckland 4, New Zealand.

Dear Mr. Fuller,

Your letters in AYRS 90 are very interesting and useful.

I have ordered a couple of the AYRS Airsfoiler hulls, since in addition to outrigger foil stabilizing of a monohull, these hulls seem to me to be very useful for tests with catamaran arrangements.

In one letter, Michael Ellison told me that he had observed that one face of a foil ran dry. In other words, the foil is acting like a planing surface inclined at an angle. Did you have the same experience? It is important, because we have been thinking along hydrofoil lines. If these shapes are planing then the craft is not a hydrofoil stabilized monohull, but is a HYDROPLANE stabilized monohull, and describing the device as a foil misleads. I suppose that his weather foil was clear of the surface.

Next point. There is all this complicated behaviour with centres of effort on the foil (plane?), moving as the boat pitches and rolls, and as waves pass.

I have been doing model tests, using towed models, towing line from up the mast, including at an angle to simulate capsizing moment. I allow the catamaran hulls, and the trimaran floats, to pitch freely and independently. I do this also for tests when fixing on foils.

In this way, I have avoided all torsional stresses in the beams.

It might be possible to devise a foil (plane?) which can pitch freely. Also possible to include a vertical axis to remove yaw influences.

This brings me to the next point. If the foil is acting as a hydroplane, then why not use it flat, and put a centre plate under the hull?

Sketch below shows this concept. It is one which I hope to test.

It reverts to the catamaran when the hydroplane is made buoyant and a bit larger, and the opposite one removed. See sketches.

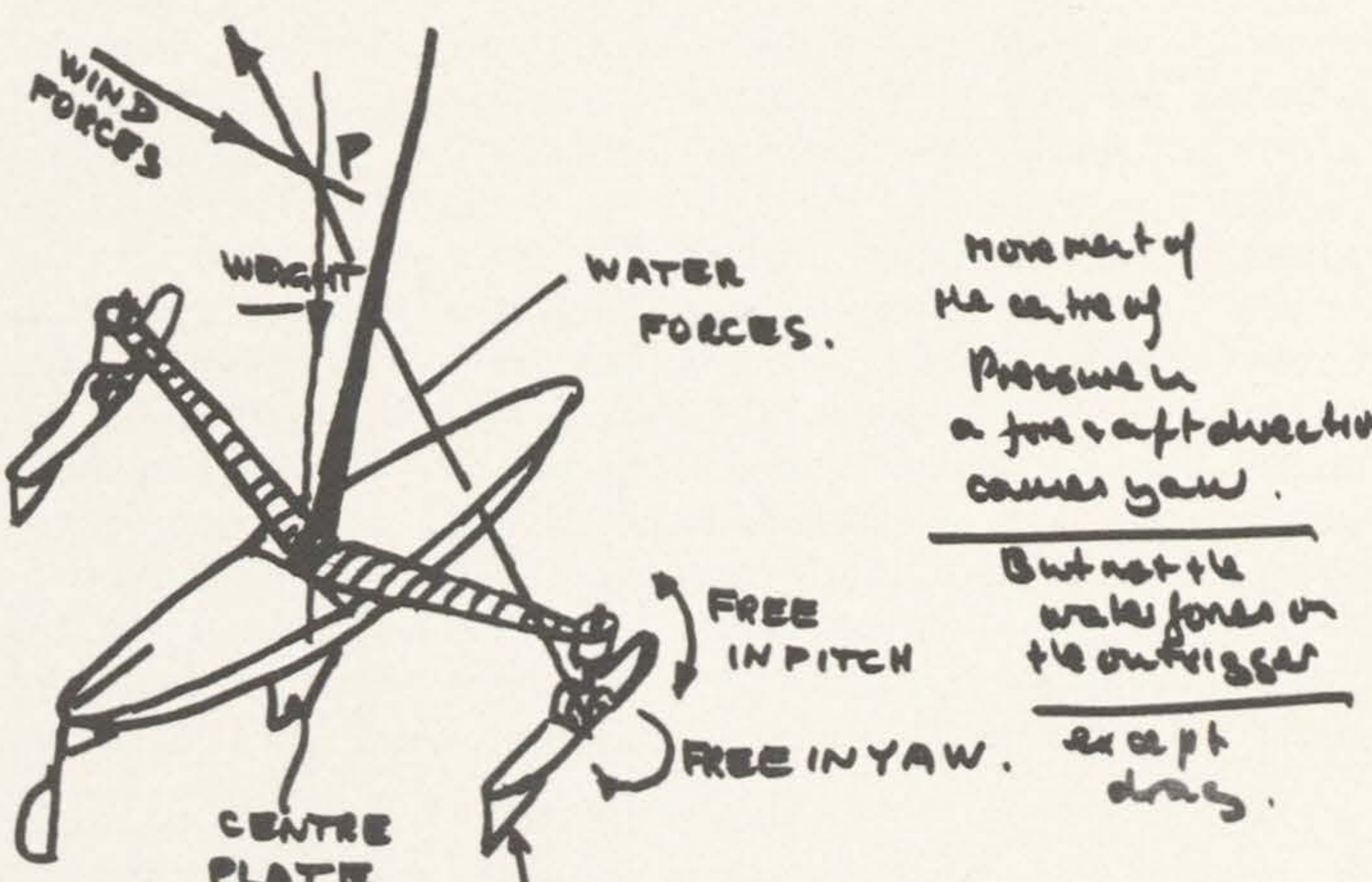
If you couold devise a way for the outrigger foils to pitch freely, this removes torque, and the upward lift MUST be at the hinge. If the foil also hinges about a vertical axis, weathercocking in line with the water flow, this removes yaw effects.

I am not suggesting that you try these arrangements. Only that they contain some new ideas, which you might be able to utilise, probably in another way.

With my best wishes for the success of your very interesting developments, and I look forward to reading further reports.

We envy you the climate. At the moment here, thick fog, freezing, airports closed. Still, we do have a lot of very nice sea around. My own aim is not so much to build a particular sort of craft, but to try out different arrangements.

Yours sincerely, Reg. Frank



Letter from Noel Fuller, 7 John Davis Road, Auckland 4, New Zealand.

To John Morwood, Woodacres, Hythe, Kent, U.K. 26th January, 1979

Dear John,

I am very anxious to know how your experiements with your semi-ellipse sail are proceeding. I am just about to start building one, having satisfied myself with models that it is a very good sail.

You will recall that when I put a wishbone boom on "Sabrina" I found her to be underbalanced, resulting in reduced performance. To compensate for the extra height of the sail centre of effort induced by the wishbone boom I renewed the telescoping beams and initially extended them 20 cm. 'Sabrina' was so overbalanced as to be unsailable having enormous stability and little lateral resistance. Bernard Rhodes is going to use this condition later to investigate windward performance while using a leeboard. I shortened the beams until they were only 2.5 cm. out from their original position. At this point 'Sabrina' balances beautifully. I am rather stunned that the relationship is so critical but put this down to the very low aspect ratio of the foil mudflat foils. That is, a small change in heel results in a large change in foil area. Now 'Sabrina' will happily carry 9.1 m^2 of sail in fresh to strong winds although fastenings are having to be strengthened.

Recently I sailed her in winds of 20 to 30 knots including a number of miles downwind in difficult seas. The foiler must be handled in a way which would be very naughty on other craft. The trick to downwind sailing is to use the foils to throw up the bow at the right moment. 100% concentration is required. As the bow begins to submerge in the wave ahead, I use the rudder to bear upwind a little. This causes the lee foil to lift the nose. With a tweak of the rudder downwind again 'Sabrina' is surfing. If pitchpoling is imminent I put the helm hard over and broach. The full weight of the sail is taken by the foils and all is well. A powerfull rudder is required in the case of a canoe stern. A transom would, I think, be easier to shift.

With the wind at 30 knots, I put in a leg to windward at about 60 degrees True, carrying full sail. The result was astounding and exhiliarating. With the assistance of the wave tops, 'Sabrina' leapt clear of the water and accelerated madly sailing on the lee foil and rudder tip with me sitting out to windward. (The outboard seats are very useful). The spectacular crashes on wave tops and a nasty lee shore soon induced caution. However, a very interesting feature emerges. The shrouds during sailing over nearly 20 miles, had severely stretched my rather lightweight galvanised wire understays to the aft beams. Consequently the lee foil was suspended only by the forward beam which itself has negligible torsional resistance. The aft beam was acting merely as a spacer. The lee foil did not gyrate, nor were its movements any large part of the total movement allowed by the slack shroud and understay. One of the accompanying photographs clearly shows the typical extreme of such movement. Bernard Rhodes is at the helm.

W. R. Frank of Barnsley, Yorks., has asked me if 'Sabrina's' foils do in fact act as inclined hydroplanes with one side running dry. The boards are 60 cm. from top to bottom. About 15 cm. of the inboard face of the lee foil is always wet but it does not seem to generate any lift as I have indicated before. I think the short answer is that a very low aspect ratio board is indeed an inclined hydroplane while it is to leeward. However, it does foil when to weather. In a seaway, the weather foil is quite active off the wind. Higher aspect ratios in the neighbourhood of one are quite definitely foils provided suitable sections are used and the finishing is good. I think very low aspect ratios are inefficient.

AN ASYMMETRIC HULL FOR A FOILER

In investigating ideas for a new foiler of about 9 metres L.O.A. I made two models. Both have transoms, rounded sections, identical non-twisting semi-ellipse sails and each has a single semi-ellipse hydrofoil whose projected working area is of aspect ratio I.I. and 3.5% of sail area. This foil slots into a thin inclined float which is shaped so that it avoids pitching out of a wave. At full size this float would support the beams and foil with at least 90 kgms. reserve buoyancy. It would also be able to operate as a low aspect ratio lee foil in shallow water. The second model differed chiefly from the first in having an asymmetric hull based on a kelson curved on an arc of a circle. The kelson displacement was 1.43% of L.W.L. Other lines were faired to suit. The kelson curved away from the foil.

The models were compared in a small swimming bath using both towlines and sails in scale winds from light to fresh. No exact measurements were made. They were also sailed in a small bay in scale gales. I expected the asymmetric model to balance better and to sail higher than the other when on the weather tack (foil to weather). The actual performance astonished and delighted me. The following observations were made:

(1) The asymmetric model sailed about 5 degrees higher than the other and footed faster to windward ON BOTH TACKS! There is a stunner!

(2) The asymmetric model was able to accept gusts without capsize when the foil was to weather. The symmetric model capsized in fresh gusts if it was not moving.

(3) The asymmetric model pitchpoled when reaching in strong gusts on a lee tack (foil to leeward). The symmetric model remained stable.

(4) BALANCE: Both models sailed straight on all courses when rudders were used. With their pantographing beams each could be balanced for sailing on both tacks without rudders. The symmetric model balanced with the foil abeam of the mast on the lee tack but with the foil well aft on the weather tack. Eight degrees of rudder were required on the weather tack to balance the boat when the foil was left in the lee tack position. The asymmetric foiler required much less shift in the foil position when balanced without the rudder. With the foil positioned for the lee tack, the rudder correction for the weather tack was attained with the tiller fore and aft.

(5) FOIL ALIGNMENT' Pitchpoling was minimized and speed greatest for both tacks when the foil for the asymmetric model was parallel with the chord of the kelson curve. This line runs from the cutwater to the centre of the 75% transom and is what I take to be 'fore and aft' on an asymmetric hull.

A further point of interest concerns tow-out of the foil on the asymmetric model. As tow-out was increased on the weather tack the model became vulnerable to capsize. This suggests that the lift to drag ratio may be an important factor in the stability equation.

It would be unwise to draw firm conclusions from the above observations as too much remains to be tied down. I maintain in my own mind some reservation toward the observations themselves. Nevertheless, I am tempted to the belief that asymmetry for a foiler has been shown to be worth investigation. Below I attempt some explanation for the behaviour of my model and hope that others may be in a position to illumine the matter further.

Two types of asymmetry tend to be used in hulls. They are quite different. That which is based on a straight kelson with one side fatter than the other reflects ideas about lift to windward as in foils. Lift tends to be generated in the forward part of the hull. If so, this type of asymmetry would prove incompatible with a foiler. The other approach originating in micronesia, is based on a curved kelson. This is not intended to produce lift to windward but is intended to steer the hull away from the float so as to counteract its drag and so allow a straight course to be sailed. The lateral resistance of a Micronesial proa is all provided by the hull. In other than running courses the curved kelson causes the forward half of the hull to tend toward a running course while the after half provides lateral resistance. The lift to drag ratio of the hull is probably better than that of a straight hull of similar section on the same course.

The Bruce foiler or mono-foil differs radically from the Micronesian proa in having its lateral resistance concentrated in the foil instead of in the hull. I supposed that only a touch of asymmetry was required to effect a balance of the boat for both tacks thus allowing me to get away with rounded sections, a transom and a fairly flat run aft. The concentration of hull lift aft and the reduction of drag forward is enough, I believe, to explain the superior performance of this model while on the WEATHER TACK. The effect on BALANCE is to allow the foil to be further forward than it otherwise would.

When the foil is to lee (lee tack) hull lateral resistance is concentrated toward the bow which assumes a fairly high angle of attack to the course. The effect on BALANCE is to cause the foil to be positioned a little further aft than it otherwise would. The tendency is to produce a foiler which can be steered by the mainbrace (or sheet) on both tacks without adjustment of the mast or foil. This model fell short of this goal but is a substantial step toward it. The pitchpoling on the lee tack is due to the piling up of a wave under the bow (lee bowing). The stern lifts, speed increases, the wave grows larger, the bow catches and over she goes. In scale terms this phenomenon occurs only in strong winds. However, it cannot be ignored. High performance craft generate their own strong winds. The bow sections of the model are excessively fine forward – something difficult to avoid with curved kelson asymmetry. I am hopeful that the pitchpoling phenomenon may be eliminated by broadening the bow sections and radiusing the kelson forward. It may be a problem to achieve this without losing the benefits of asymmetry. An asymmetric tacking monofoil seems just about the most complex craft to design that I can think of.

Yours, Noel Fuller.

ANALYSIS OF SAILING VESSEL PERFORMANCE RATIOS AND THEIR SYNTHESIS

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Introduction
This paper presents a method of proof that the speed of all sailing vessels are comparably a function of their waterline lengths, sail areas, and displacements.

An analysis of the $S/\sqrt{LWL}$ of 39 sailing vessels of many different types and an analysis of their speeds related to their Bruce numbers led to a synthesis of these two ratios producing an equation for predicting the best, average daily speed of any sailing vessel.

To standardize speed for the analyses and the synthesis, the average speed of a day's run was chosen because a day is the smallest duration for which distances sailed have been regularly recorded throughout the past one or two centuries. Also, the speed calculated from a day's run has considerably more accuracy and precision than does the measurement based on counting knots with a ship's log or even the observation of a momentary flick of the speedometer's needle on one of today's racing yachts.

Measurement
The following decisions were made about the measurements of waterline length, sail area, and displacement in an attempt to standardise the data both within and between the various classes of sailing vessels.

Waterline length was the least problematic of the three measurements. Transom mounted rudders were included as part of waterline length.

The measurement of sail area was perhaps the most difficult to standardise. Because several of the multihulls have large roach areas, these areas on the fore-and-aft sails for all appropriate vessels were included in the measurements. The roach area was sonsidered as 2/3 of the roach depth times the straight line distance between the peak and clew. In a few cases where batten lengths were known (IOR rating certificates), one-half of the largest batten length was used as roach depth. In cases where the foresail(s) area was less than the foretriangle area, the former was used. For the square rigged vessels, the areas of their interior stay-sails and the studding sails were not included.

Displacements were generally taken as given by the various references. The displacements of some of the larger vessels were calculated with the trapezoidal rule which can be found in most references on naval architecture. For KON TIKI, the volume of her balsa logs was estimated and combined with an estimate of their percent submersion to obtain displacement.

Vessel Descriptions
Tables 1–4 present the data for 39 sailing vessels of all shapes, sizes and rigs. Also presented in these Tables are some other pertinent values calculated from this data. Although it is not necessary to go into details about each of these vessels, some description or distinction of each will be made so that they will represent more than just names and numbers. For those readers wishing to know more about any particular vessel, the references have been numbered, and these reference numbers have been listed for each vessel in the Tables.

In chronological order, the first group whose data is listed in Table 1 are the replicas. As it is nearly impossible to find either the measurements or the daily runs of sailing vessels dating prior to the 1800's, our data needs can be filled by the replicas of pre-1800 sailing vessels. The MAYFLOWER II now docked in Plymouth Harbour, Massachusetts, represents an Elizabethan cargo-galleon of the 17th century. A replica of a 2000 year old Chines junk, TAI Ki, sailed through a succession of typhoons in an attempt to prove that ancient oriental mariners once voyaged from East Asia to Central and South America. Built for the U.S. Bicentennial, HOKULE'A, a replica of a Polynesian double canoe sailed from Hawaii to Tahiti and return. Thor Heyerdahl's RA built of reeds and KON TIKI built of balsa logs are perhaps the most primitive and famous of the replicas. BRENDAN is an Irish skin boat (curragh) that was sailed across the North Atlantic to demonstrate that the mediaeval Irish Monk, St. Brendan, could have used such a craft to sail to America, thereby predating the "discovery" of New World by either Columbus or the Vikings.

Table 2 contains the data on the second group, the square and schooner rigged vessels that represent the "Great Age of Sail." Although several 5-masted barks were built before steam replaced sail, the steel PREUSSEN was the only 5-masted ship ever built. HERZOGIN CECILIE, a steel 4-masted bark was built as a cadet training ship yet carried cargoes of grain from Australia to Europe. The composite built tea clippers, CUTTY SARK, and THERMOPYLAE should need no introduction. The wooden FLYING CLOUD, perhaps the most well-known of the American clipper ships, sailed from New York to San Francisco in 89 days. The American racing schooner, WESTWARD, competed against the famous British cutter, BRITANNIA, in the 1920's and 1930's. GERTRUDE L. THEBAUD is a a fine example of a

Gloucester fishing schooner. The schooner yacht, AMERICA, began the America's Cup Races by defeating the best British yachts in 1851. Although she is a "modern" yacht, VARUA is included in this group because of her brigantine rig.

The third group of sailing vessels, twelve monohull yachts, are listed in Table 3. Note that an additional column has been added to Table 3 (also 4) indicating whether the yacht was either crewed (c) or sailed (s) when the day's run was made. The first two yachts, ONDINE III and KIALOA III are IOR maxi-ketches that have swapped line honors in many ocean races. HEATH'S CONDOR was the favourite for the 1977-78 Whitbread Round the World Race, but finished fifth. Eric Tabarly's aluminium ketch. PEN DUICK VI has spent uranium for ballast and has therefore been prohibited from IOR racing. WINDWARD PASSAGE, is another successful maxi-ketch that has raced throughout the world. The old 12-Meter, EVAINE, has been converted for cruising. Bill Lee's MERLIN is one of the first of a new class of monohulls, the ultralight displacement boats (ULDB). FLYER won the 1977-1978 Whitbread Round the World Race on corrected time. Sailed by Geoffrey Williams, SIR THOMAS LIPTON won the 1968 OSTAR. Sir Francis Chichester was knighted for solo-sailing GIPSY MOTH IV around the world. Joshua Slocum's SPRAY was the first vessel sailed solo around the world. Tabarly's fifth PEN DUICK has compartments into and out of which water can be pumped for ballast.

Listed in Table 4, the final group of sailing vessels are the multihull yachts. The first is another of Tabarly's PEN DUICK'S, a trimaran which Alan Colas renamed MANUREVA and sailed solo around the world in 169 days. Rudy Choy designed the catamaran, SEASMOKE, for the T.V. star, James Arness. AIKANE and PATTY CAT II are two other catamarans designed by Choy. Although she did not reach home, VICTRESS was the first trimaran to have been sailed around the world. The Dick Newick design, CHEERS, has been the only successfuly raced proa. The catamaran, REHU MOANA, was the first multihull to sail around the world. For transport across the United States, the trimaran HURRY KANE was sawed into pieces then reassembled in California. THREE LEGS OF MANN was also attacked with a saw; 18 inches was cut off the bow of her main hull so that she would qualify for the under 35 foot class of the Round Britain Race. The trimaran WILLIWAW, is unique in that she is the first successful, ocean-going hydrofoiled sailing vessel.

Analysis of $S/\sqrt{LWL}$

Naval architects have long accepted as fact that a sailing vessel's speed is primarily a function of her waterline length. Mathematically, this relationship can be expressed with the equation:

$$S = \alpha \sqrt{LWL} \qquad (1)$$

where S is speed measure in knots, LWL is length on waterline measured in feet, and a is some constant or factor. Rearranging equation (1) as:

$$\alpha = S/\sqrt{LWL} \qquad (2)$$

a can be easily seen as the ratio that has been used as a measure of a sailing vessel's performance relative to her waterline length.

When a equals 1.33, naval architects have asserted that a sailing vessel has reached her maximum speed through the water – hull speed. If a sailing vessel were to momentarily exceed this speed barrier, they would say that the vessel was no longer displacing water but planing. Even after the advent of multihulls which were capable of exceeding their "hull speed" for more than just a few minutes, such performances were also explained as planing. But, if they had viewed a multihull at speed, they would have realised that she was not necessarily planing.

Furthermore, some of the data presented in Tables 1–4 and plotted in Figure 1 should lay to rest the mistaken maxim of a hull speed barrier. Even excluding the multihulls whose data points have been left open for greater distinction, one can see that many of the vessels have exhibited an average speed for 24 hours that is over their theoretical hull speed. There is not even a slight indication of a barrier along and near the dashed line such as a build-up or a gap in the points.

Also, Figure 1 indicates that there is little correlation between speed and waterline length; at least not as much as one would have been led to suppose. Perhaps, if data were available for sailing vessels with waterline lengths ranging from about 120 to 190 feet., a greater correlation may have been realized. But still there is a great range in the speed for the 36 to 50 foot vessels which is rather strong evidence that other parameters have a greater bearing on a sailing vessel's speed than does solely her waterline length.

Analysis of Bruce Number

Two other parameters known to affect a sailing vessel's speed are her sail area and displacement or weight. The ratio of these two parameters is basically the power to resistance characteristic of a sailing vessel. Presumably, this ratio was first determined by Enmond Bruce and presented in the AYRS publications of the early 1970's. Known, therefore, as the Bruce number, the proportionality is:

$$\sqrt{A_S} \Big/ \sqrt[3]{W} \qquad (3)$$

where A_S is the sail area measured in square feet and W is the displacement measured in pounds.

Figure 2 is a plot of the Bruce numbers versus the average daily speeds of the 39 sailing vessels presented in Tables 1–4. Excluding the five largest square riggers whose points have been left open, it is very obvious that the average daily speed of the rest is highly related to their Bruce number.

Without the five square riggers, a regression analysis of these data indicates that their linear relation can be expressed as:

$$S = 2.081 + 10.639 \text{ Br} \qquad (4)$$

having a correlation coefficient of 0.863. Although this equation (dashed line in Figure 2) appears to be suitable in the practical range of Bruce numbers, it fails in the lower limit, i.e., as the Bruce number approaches 0, speed takes on an unrealistic negative value. Ideally, an equation (line) which goes through the origin is desired; therefore, a least squares fit to a power curve was applied to the data of the 34 vessels. This resulted in the equation:

$$S = 8.166\ Br^{1.375} \tag{5}$$

having a correlation coefficient is 0.892. Because equation (5) not only meets the criteria of passing through the origin but also has a higher correlation coefficient than does equation (4), equation (5) is the better of the two.

The Synthesis

The original thought behind this analysis was the hypothesis that a from equation (1) is related to the Bruce number. As can be seen in Figure 3, the data supports this hypothesis. Special note should be taken that the five square riggers that stand apart from the rest in both Figure 1 and 2 are now aligned with them. Subjecting all the data to a regression analysis, the linear relationship is found to be:

$$\alpha = S/\sqrt{LWL} = -0.603 + 1.800\ Br \tag{6}$$

having the high correlation coefficient of 0.928. Again a least squares fit to a power curve is made in order to have a line passing through the origin. The power curve fitting all the data is:

$$\alpha = S/\sqrt{LWL} = 1.167\ Br^{1.459} \tag{7}$$

which has yet a higher correlation coefficient of 0.944.

By analysing the data of just ten best performers (KON TIKI, BRENDAN, HOKULE'A, PEN DUICK V and VI, FLYER, HURRY KANE, MANTA II, THREE LEGS OF MANN, SEA BIRD) two other equations are obtained:

$$S/\sqrt{LWL} = 0.484 + 1.906\ Br \tag{8}$$

and

$$S/\sqrt{LWL} = 1.366\ Br^{1.425} \tag{9}$$

having correlation coefficients of 0.997 and 0.998 respectively. The power curve equation (9) is again the better equation because it passes through the origin and has the higher correlation coefficient.

A simple algebraic rearrangement of equation (9) and the substitution of (3) for Bruce number yields the following equation:

$$S_{24} = 1.366\sqrt{LWL}\ \left(\sqrt{A_S}\,/\,\sqrt[3]{W}\right)^{1.425} \tag{10}$$

which can be used to predict the average speed of the best day's run for any tupe of sailing vessel. A subscript, 24, has been added to the speed term to denote that the speed is the average for 24 hours.

It follows that a sailing vessel's best average speed for any period of time, t, could be estimated using the general equation:

$$S_t = \beta\sqrt{LWL}\left(\sqrt{A_S} \Big/ \sqrt[3]{W}\right)^{\nu} \tag{11}$$

if β and ν were known. Perhaps, future analyses will reveal β's and ν's for various time periods.

Sensitivity of S to LWL, A_S, and W

Using equation (9), the sensitivity of the predicted average daily speed to changes in waterline length, sail area, and displacement was tested using the following three hypothetical vessels which somewhat span the possible range of sailing vessels.

a/ LWL – 30 ft.; A_S – 600 sq. ft.; W – 4000 lbs.
b/ LWL – 80 ft.; A_S – 3000 sq. ft.; W – 100,000 lbs.
c/ LWL – 360 ft.; A_S – 50,000 sq. ft.; W – 2.0 x 10^7 lbs.

The predicted speeds of each was calculated then compared to those speeds resulting from a + 5% change individually in each of the three measurements. These eighteen comparisons indicate that a 5% change in waterline length causes approximately a 2.5% change in speed, that a 5% change in sail area causes approximately a 3.5% change in speed, and that a 5% change in weight causes approximately a 2.4% change in speed. Obviously, increases in waterline length and sail area cause increases in speed, whereas an increase in weight causes a decrease in speed.

Conclusions

1. The barrier of hull speed exists only in theory.

2. Sailing vessels can plane, but they need not do so in order to sail faster than 1.33 LWL. Although not having total dynamic support upon the water's surface, vessels going at such speeds may be experiencing Partial Dynamic Support. (PDSing vs. planing).

3. The high correlation coefficient of equation (7) indicates that most of a sailing vessel's speed can be attributed solely to her LWL, A_S, and W. It follows therefore that the major advances in sailing vessels up through the centuries as pertaining to the increase of their speed are those which have enabled waterline length and Bruce number to be increased.

4. The speed of monohull and multihull yachts are similarly effected by changes in LWL, A_S, and W, therefore there can be an equitable rating system based on these three parameters that can be used for both.

5. The percent increase in speed that can be attributed to an increase in LWL and A_S and the percent decrease that is due to an increase

in W could be combined with the monetary and weight costs of LWL and A_S increases to help determine the most effective design for speed.

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Table 1. Replicas

	Length (ft-in)		Sail Area (ft^2)						Displace.	Day's Run	Speed	$S/\sqrt{LWL}$	Br. #	$\frac{S/\sqrt{LWL}}{Br. \#}$	References
	hull	WL	fore△	fore	main	mizzen	jigger	total	(lbs.)	(N. M.)	(knots)				
Mayflower II	106-8	79-9	459	1452	2542	649	–	5102	8.18×10^5	164W	6.8	0.76	0.76	1.00	1-3
Tai Ki	64	42	–	–	1188	–	–	1188	69,440	98E	4.1	0.63	0.84	0.75	4
Hokule'a	62-4	54-0	–	–	310	230	–	540	25,000	185	7.7	1.05	0.79	1.32	5
RA	50*	45*	–	–	494	–	–	494	45,000	80W	3.3	0.50	0.62	0.80	6
Kon Tiki	45	45	–	–	350	–	–	350	65,000	71W	3.0	0.44	0.47	0.95	7
Brendan	36-0	30-0	–	78	185	–	–	263	11,200	115W	4.8	0.87	0.72	1.21	8

*Scaled from photographs

Table 2. Square and Schooner Rigged Vessels

	Length (ft-in)		Sail Area (ft^2)							Displace.	Day's Run	Speed	$S/\sqrt{LWL}$	BR. #	$\frac{S/\sqrt{LWL}}{Br. \#}$	References
	hull	WL	fore△	fore	main	middle	mizzen	jigger	total	(lbs.)	(N. M.)	(knots)				
Preussen	444	407-10	2540	10,980	11,630	11,350	10,975	8475	55,950	2.50×10^7	370W	15.4	0.76	0.81	0.94	9-12
Herzogin Cecilie	336	310	5100	11,350	11,350	–	11,350	4850	44,000	1.44×10^7	365	15.2	0.86	0.86	1.00	13-16
Cutty Sark	240	213	3250	7,050	8,350	–	6,200	–	24,850	4.78×10^6	363	15.1	1.04	0.94	1.11	3, 17-20
Thermopylae	231-6	210	4270	7,150	7,890	–	6,200	–	25,510	4.41×10^6	358E	14.9	1.03	0.97	1.06	17-22
Flying Cloud	235	209-6	2850	6,200	7,470	–	4,340	–	20,860	4.37×10^6	374W	15.6	1.08	0.88	1.22	23
Westward	135	96-1	3500	2,200	6,100	–	–	–	11,400	7.24×10^5	272E	11.3	1.16	1.19	0.96	24
Gertrude L. Thebaud	132-7	98	1850	2,000	4,310	–	–	–	8,160	4.57×10^5	315E[1]	13.1	1.32	1.17	1.13	25, 26
America	101-9	90-3	1190	1,820	2,253	–	–	–	5,263	3.82×10^5	284E	11.8	1.25	1.00	1.25	27, 28
Varua	74	60	505	810	1,385[2]	–	–	–	2,700	1.12×10^5	233	9.7	1.25	1.08	1.16	29

[1]Based on her 400 N. M. run from Gloucester to Halifax in 30.5 hours.

[2]Includes staysails.

Table 3. Monohull Yachts

		Length (ft-in)		Sail Area (ft^2)				Displace	Day's Run	Speed	$S/\sqrt{LWL}$	Br. #	$\frac{S/\sqrt{LWL}}{Br. \#}$	References
		overall	waterline	fore △	main	mizzen	total	(lbs.)	(N. M.)	(knots)				
Ondine III	C	88-4	72-0	1081	783	784	2646	81,950	293E	12.2	1.44	1.18	1.21	30-33
Kialoa III	C	78-10	64-0	1272	1020	586	2878	83,800	270W	11.3	1.41	1.23	1.15	34-36
Heaths Condor	C	77-0	64-0	1280	1265	–	2545	87,360	297E	12.4	1.55	1.14	1.36	37-39
Pen Duick VI	C	73-0	61-10	1025	780	375	2180	70,550	305E	12.7	1.62	1.13	1.43	40
Windward Passage	C	72-9	65-0	1303	914	270	2487	80,000	262	10.9	1.35	1.16	1.17	41, 42
Evaine	C	69-11	45-6	1000	1200	–	2200	60,000*	235	9.8	1.45	1.20	1.21	43, 44
Merlin	C	66-6	62-0	773	818	–	1591	21,500	326W	13.6	1.73	1.43	1.21	45-47
Flyer	C	65-2	49-9	903	612	312	1827	55,300	280	11.7	1.65	1.12	1.47	48-50
Sir Thomas Lipton	S	56-2	42-0	594	408	150	1152	27,440	211W	8.8	1.36	1.13	1.21	51, 52
Gipsy Moth IV	S	54-0	38-6	420	289	143	852	25,760	192E	8.0	1.29	0.99	1.30	53
Spray	S	36-9	32-1	406	604	151	1161	36,000	150	6.3	1.10	1.03	1.07	54
Pen Duick V	S	35-0	29-6	312	268	–	580	7,170	240W	10.0	1.84	1.25	1.47	55

*Estimate based on other 12-Meters.

Table 4. Multihull Yachts

		Length (ft-in)		Sail Area (ft^2)				Displace.	Day's Run	Speed	$S/\sqrt{LWL}$	Br. #	$\frac{S/\sqrt{LWL}}{Br. \#}$	References
		overall	waterline	fore △	main	mizzen	total	(lbs.)	(N. M.)	(knots)				
Manureva (Pen Duick IV)	S	69-10	66-6	480	587	409	1476	19,000	326E	13.6	1.67	1.44	1.16	56
Seasmoke	C	57-9	48-6	740	808	–	1548	21,170	331W	13.8	1.98	1.42	1.39	56-58
Aikane	C	46-0	41-0	375	540	–	915	11,000	306E	12.8	1.99	1.36	1.46	59, 60
Sea Bird	C	45-0	35-1	356	520	–	876	7,255	345W[1]	14.4	2.43	1.53	1.59	56, 61
Patty Cat II	C	43-10	36-3	414	472	–	886	8,240	316W	13.2	2.19	1.47	1.48	56, 57
Victress	S	40-0	36-0	275	270	95	640	12,000	202E	8.4	1.40	1.11	1.27	62, 63
Cheers	S	40-0	36-0	115	165	165	445	3,000	250W	10.4	1.74	1.46	1.19	56
Rehu Moana	C	40-0	35-6	495	370	–	865	17,920	198W	8.3	1.38	1.12	1.23	56, 59, 64
Hurry Kane (Ringo)	C	38-7	35-5	337	386	–	723	7,925	300W	12.5	2.10	1.35	1.56	56-58
Three Legs of Mann	S	36-6	34-0	320	270	–	590	4,480	340W	14.2	2.43	1.47	1.65	56-65
Manta II	C	33-0	30-0	285	220	–	505	4,000	285[2]	11.9	2.17	1.42	1.53	56, 66-69
Williwaw	C	31-4	28-0	140	240	–	380	3,800	195	8.1	1.54	1.25	1.23	70-73

Note: In the second column S means solo and C means crewed; in the tenth column E is for east and W is for west.

[1]Sea Bird was reported to have sailed 360 N. M. in the 1970 Multihull Transpac Race, but owner/skipper Bob Hanel has not confirmed this.

[2]Manta II holds the 309 N. M. Brisbane-Gladstone Race record of 26 hrs. 2 min. upon which her day's run is conservatively based.

Figure 1. The average daily speeds of various sailing vessels plotted against the square root of their waterline lengths.

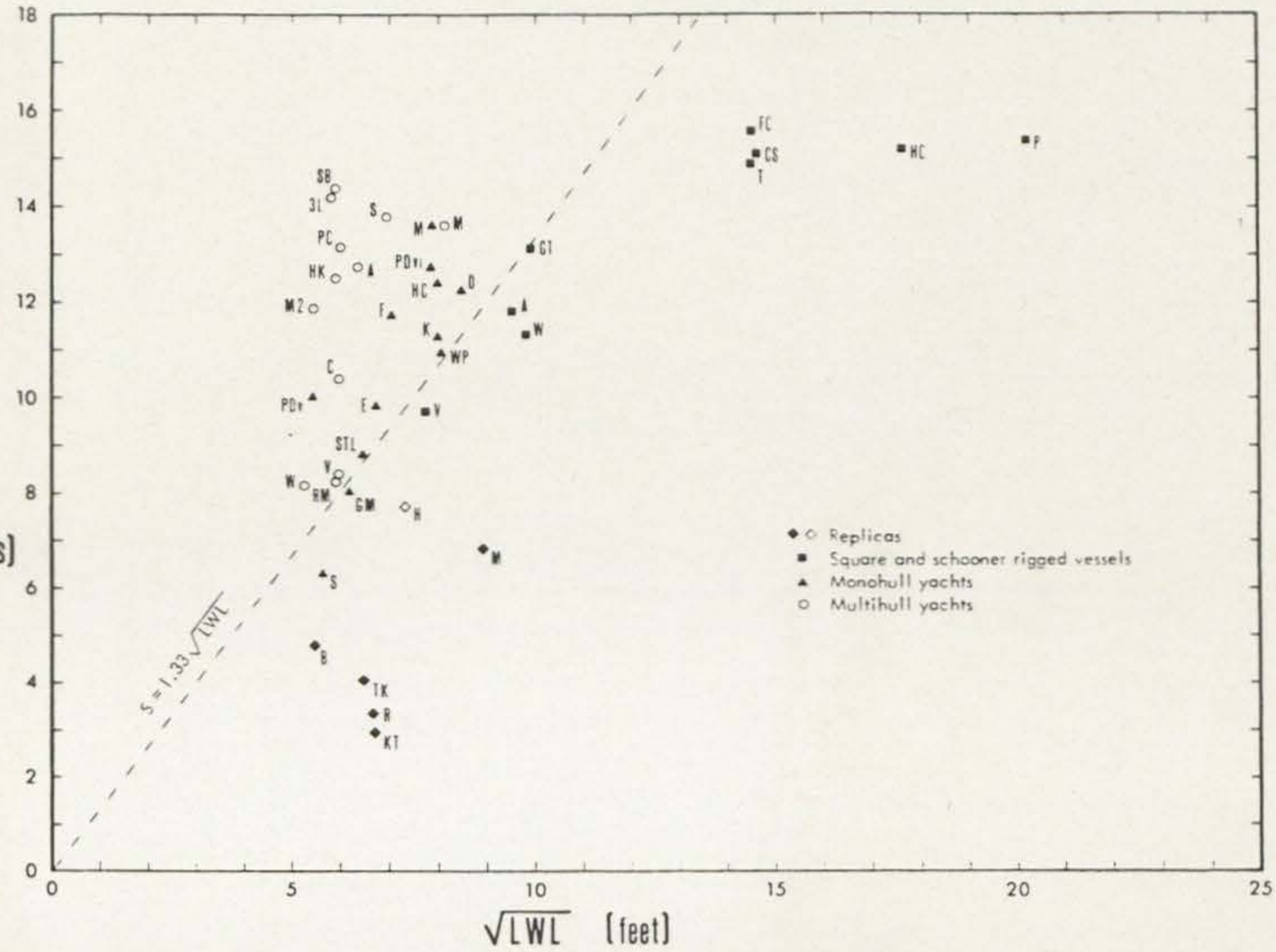


Figure 2. The average daily speeds of various sailing vessels plotted against their Bruce numbers.

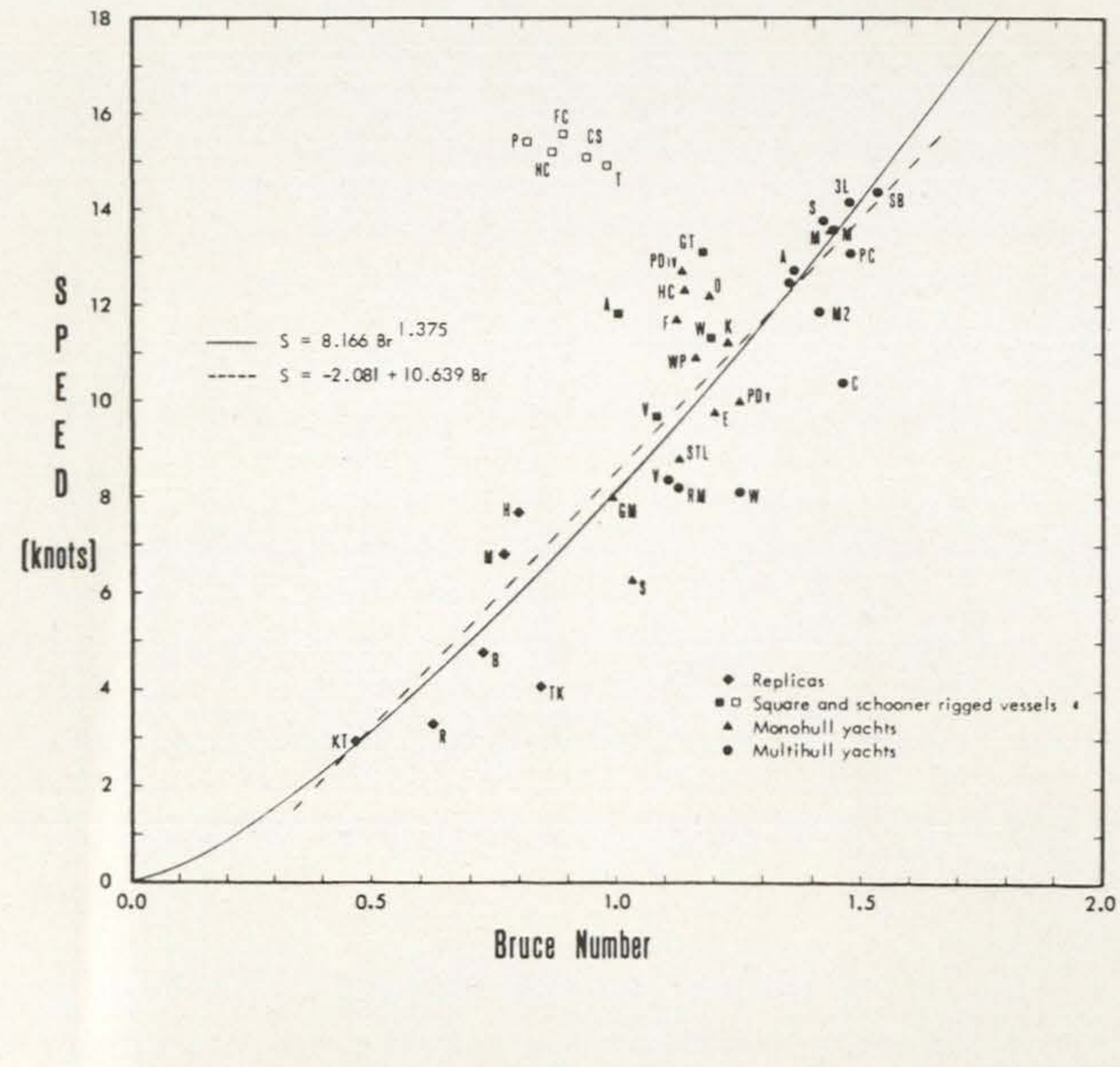
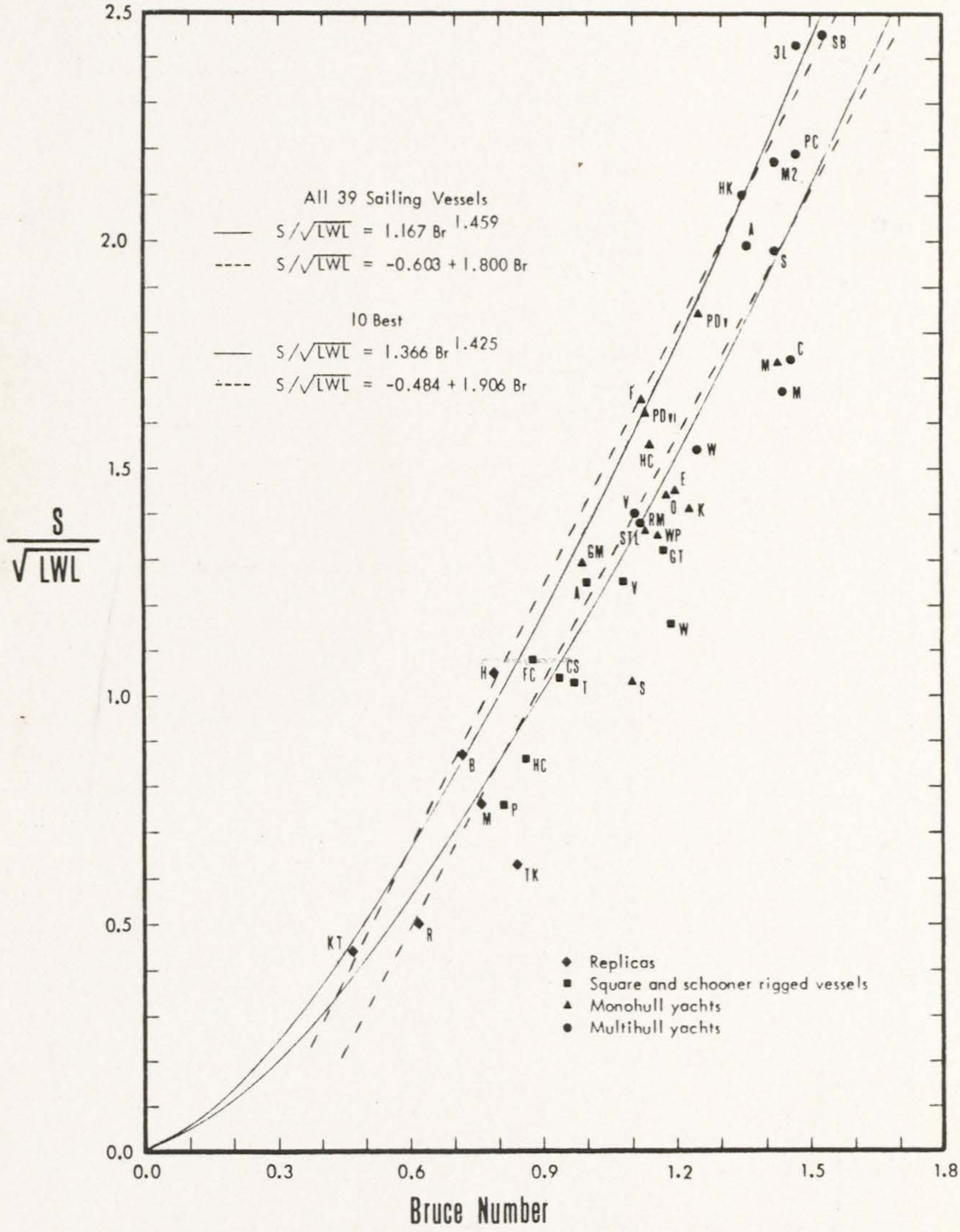


Figure 3. The ratio of the average daily speeds of various sailing vessels divided by the square roots of their waterline lengths plotted against their Bruce numbers.



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