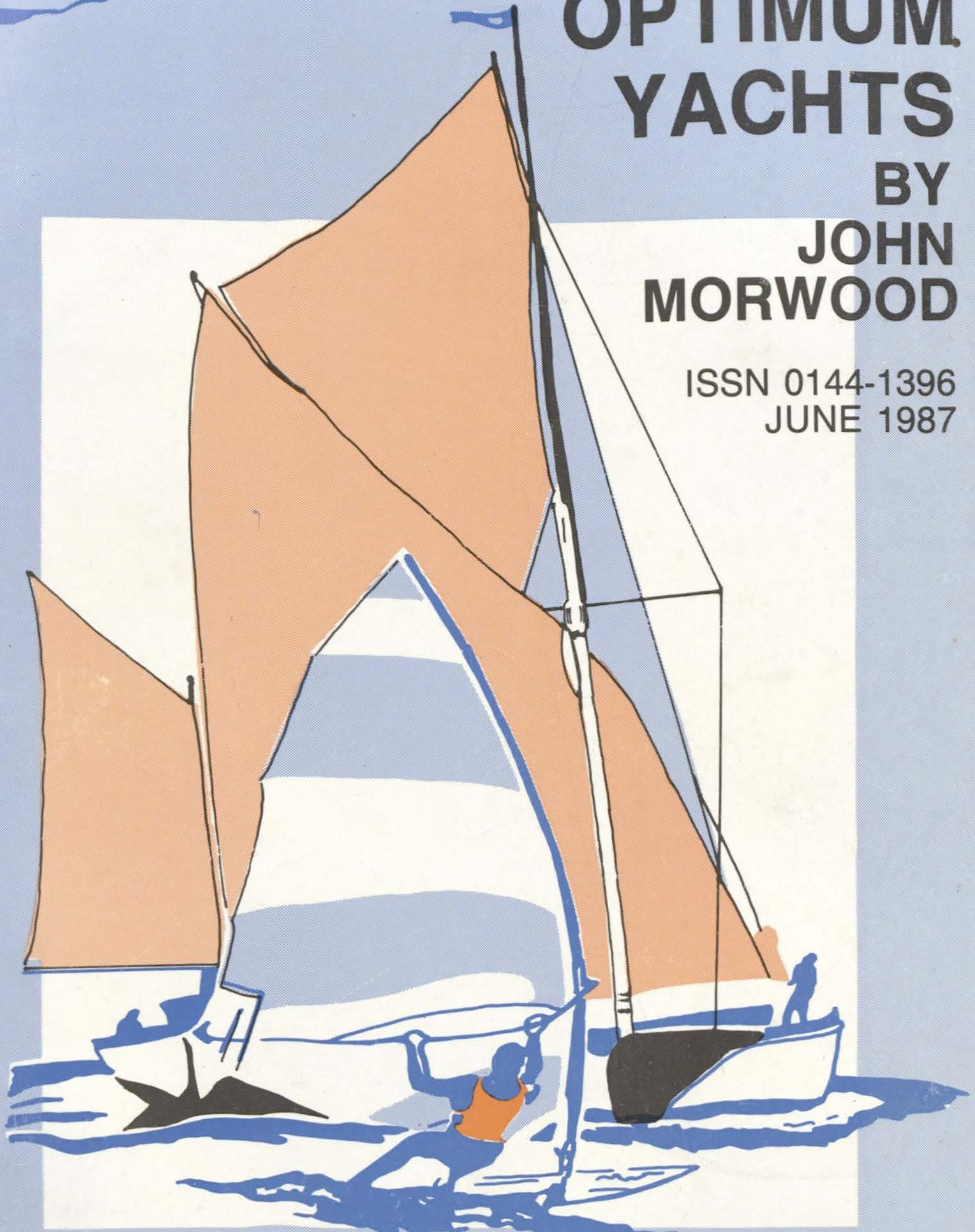
AYRS 103
OPTIMUM YACHTS

BY
JOHN MORWOOD

ISSN 0144-1396
JUNE 1987



AMATEUR YACHT RESEARCH SOCIETY

PRESIDENT: HRH THE PRINCE PHILIP, DUKE OF EDINBURGH KG KT OM GBE QSO

THE AMATEUR YACHT RESEARCH SOCIETY

Founded June 1955 to encourage Amateur and Individual Yacht Research

The Society (open membership) furthers the theory and practice of nautical science and related subjects. Educational Charity (No. 234081) and a company (No. 785327) without share capital, limited by guarantee.

Administration and Editorial Address:
10, Boringdon Terrace,
Turnchapel, Plymouth, PL9 9TQ, England

A member in Australia kindly donated the cost of printing this number

BUCKINGHAM PALACE.

Just because it is possible to drive boats with engines is no reason to give up trying to find better methods of using the wind as the means of propulsion. This type of research has a particular fascination as it also has to take the behaviour of the elements into consideration.

Members of the Amateur Yacht Research Society have been doing this for many years and some very interesting ideas have been described in the pages of its journal; some in theory and some in rudimentary practical form. Some have not been put into practice simply because the appropriate materials have not been available. With the present rapid rate of development of new materials there is always a chance that even old theories can be tried out in practice. I hope the publication of "Optimum Yachts" will stimulate members to exercise their imaginations and to try out new ideas.

Philip

1987

PREFACE

It is an honour to be asked to write an introduction to John Morwood's last work. I have for fifteen years now tried to follow in his footsteps and throughout that time I have been only too well aware of my inadequacy in following this great flamboyant and imaginative genius.

John Morwood not only spouted original ideas in the most prodigal way; he also could lead the Society he founded, with a firmness and assurance truly rare; and if all else failed he knew how to apply the goad to any sluggishness or shortcoming among less gifted mortals.

In a sense this is his 'apologia', and the the distillate of his thinking. We are all proud to be associated with this intellectual power-house - no mere doctrinaire, either, but a human of wit, humour, pungency and a readily - summoned talent of ridicule, that made up a personality on the same plane as his brain - what a rare exemplar! Indeed, a true nonpareil.

I am proud to introduce his last great work, as I am proud to have known him.

May 1987

Sir Reginald Bennett V.R.D.
Chairman, A.Y.R.S.

OPTIMUM YACHTS

John Morwood

FOREWORD

This publication is an attempt to give the speeds of yachts in relation to the various things which yachtsmen want in their boats. The first step in this research was published in A.Y.R.S. No.89, "Sailing Facts and Figures" where the speeds of many dinghies and keelboats were graphed against the square root of the length and again to the Bruce Number. (Sail Area)1/2 divided by (Displacement)1/3. These two graphs show that speeds are proportional to both but there was considerable 'scatter'. We now give these two graphs here but we also show a graph of the speeds of the yachts to the square root of the length multiplied by the Bruce number. This graph shows less 'scatter' than the other two. It could be used as the basis of a rating formula for races.

We thus can calculate the expected speeds of yachts knowing the length, sail area and displacement. The 'scatter' in the graph reveals some gems of information. For instance :-

1. Extra sail area increases speed but seems to be inefficient. We later show that there appear to be optima of sail area from 1.5 times the length multiplied by the beam for a dinghy to a figure of 0.85 for a C class catamaran.
2. Narrower dinghies are faster than beamier ones.
3. The Una rig seems to behave as if it had 30% more sail area than the sloop.

The figures for the research come from Rhonda Budd's book "Sailing Boats of the World" (Bayard Books, London).
From it, we take for each yacht the following :-
The Portsmouth Number which is the number of units of time needed to sail a fixed distance around a racing course.
The "L" or sailing length which, for convenience, I have taken to be the mean between the L.O.A. and the L.W.L.
The displacement is the weight of the boat to which I add 180 lbs. for each crew member.
Sail area, not counting the spinnaker.
The beam is the overall beam, including any flare of the topsides.

Many figures of Rhonda Budd's book are absent (usually the L.W.L., wrong or misleading beam). The overall picture, however , is good enough to show quite delicate effects of variations, as we shall see.

CONCLUSIONS.

Being able to calculate the speed of a sailing boat from its length, sail area and displacement allows us to estimate the effects of varying any parameter.

It would be a help to many people to read the A.Y.R.S. book "Design for Fast Sailing" by Edmond Bruce and Harry Morss.

INTRODUCTION

In this publication we are going to try to describe what kind of yachts people wish to have. However, we shall not be content merely to describe yachts as they now exist but will point out trends in design and possible improvements.

We will confine ourselves to sailing yachts because motor yachts are beyond my knowledge and comprehension. Even amongst sailing yachts it is almost impossible to know what people want. Everyone seems to choose a different kind of boat. I classify yachtsmen as follows :-

1. The individualist 'knockabout' sailor
2. The cruising yachtsman.
3. The racing yachtsman.
4. The ocean voyager.
5. The 'status' yachtsman.

No doubt, we all have various amounts of each of the above in us, usually unsatisfied.

As far as individual properties of a yacht are concerned, we find various often conflicting choices. The primary thing which concerns us when sailing a boat is that she shall do her best speed on the course chosen. Thus speed is the basic want. This conflicts with the cost because speed costs money and we all, I think, have limited financial means. Length gives speed and status but costs money. It also increases the effort needed to sail. Sail area also increases speed but again increases cost and effort. We all want some accommodation' on board, from a stove to make a cup of tea to berths, galley and heads if we have any size of a boat. The cruising yachtsman and the ocean voyager want yachts which have a seakindly motion. For economy and safety, many people want to keep their boats at home. The only thing not wanted aboard yachts is weight although it has to be tolerated and is sometimes useful. Cargo carrying ships, though not, strictly speaking, yachts have to be designed to carry a load.

All the above wants of yachtsmen can be classified as 'Optima'. We want speed therefore we study the way to get speed when some other factor is limited such as length, sail area, etc. The list of the optima which we will study is as follows :-

1. Speed to windward.
2. Speed/ cost ratio
3. Speed/ Home basing ratio
4. Speed/ sail area ratio
5. Speed/ length ratio
6. Speed/ displacement ratio
7. Speed/ accommodation ratio
8. Speed/ seakindliness ratio
9. Speed/ true wind speed
10. Speed/ very light winds

THE METHOD OF STUDY

Firstly we have to find out the relative speeds of yachts in general in relation to length, sail area and displacement. The formula (length X sail area)1/2 divided by (displacement)1/3 gives this.

Next, we graph a lot of boats to the formula and find which ones sail faster than expected and what different properties they have. Usually, they will be of one or more of three kinds :-

1. Prestigious racing classes are sailed faster than 'knockabout' boats.
2. The sail rig may be better.
3. The hull may have some feature such as very low windage

We then have to make a detailed study of sail area and rigs to find out the general principles of sail design. Finally, we have to study hull resistance to find the least for the purposes required.

Only after these studies have been carried out are we in a position to describe our OPTIMUM YACHTS.

THE RESEARCH INTO SPEEDS OF SAILING YACHTS.

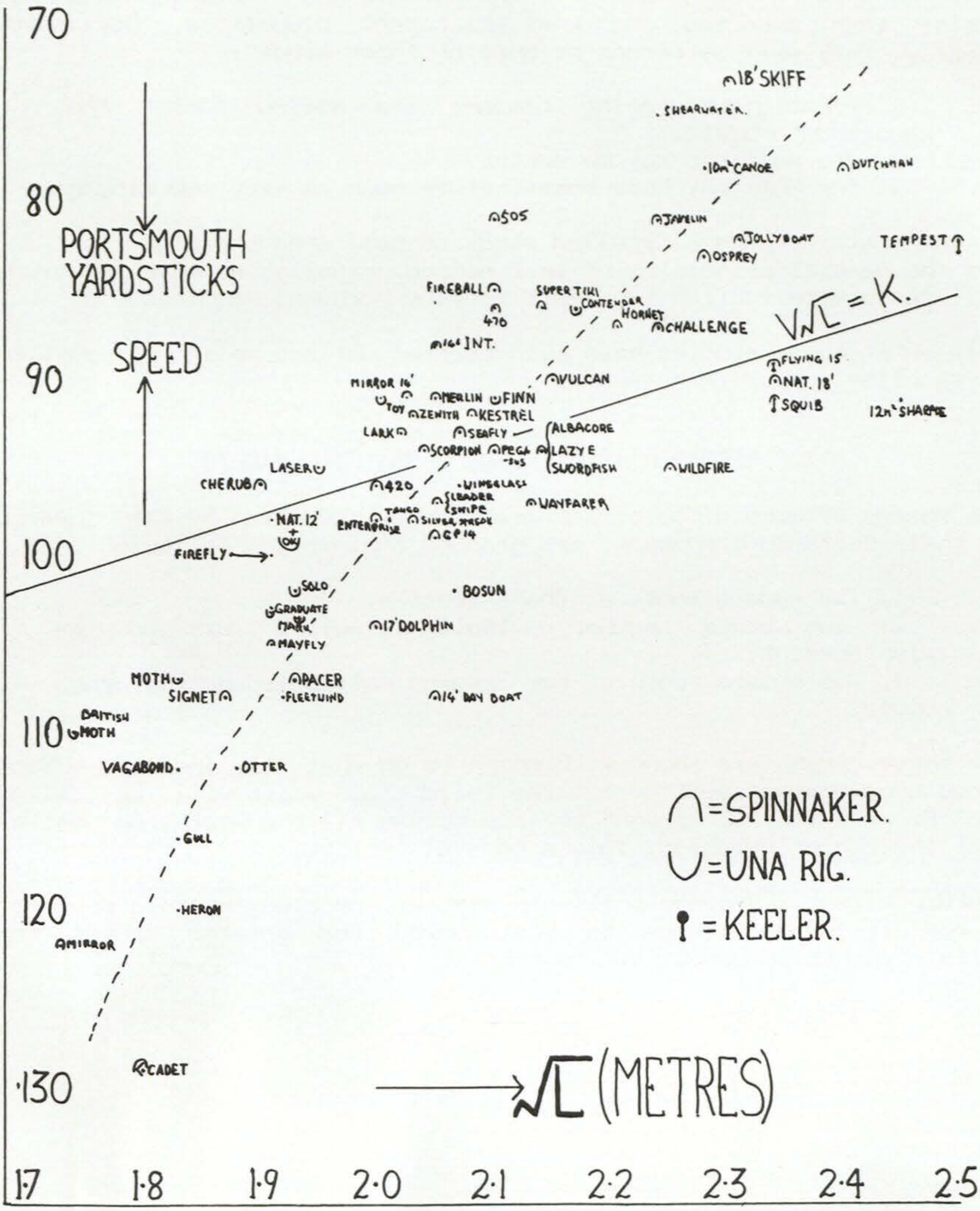
The speeds of many dinghies and keel yachts, as given by the inverse of their Portsmouth numbers, are graphed against the following :-

1. The square roots of their lengths.
2. The Bruce number, (sail area)1/2 divided by (displacement)1/3.
3. The square roots of the lengths multiplied by the Bruce number.

The three graphs are shown with comments on what they indicate. Each shows considerable scatter but the third graph which will be called the "Bruce X root 'L' graph" clearly brings all the boats, no matter what their configuration, into a general conformity.

The Bruce root "L" graph still has scatter. By studying this scatter, we can get information as to what makes for greater speeds for certain yachts in comparison to others.

THE SPEED Vs LENGTH GRAPH.



THE SPEED Vs LENGTH GRAPH.

This graph shows the following:-

1. The longer boats are faster.

2. Speed is NOT proportional to the square root of length in the boats considered. The full line gives the square root proportionality. The dotted line gives the mean curve of the boats studied. It will be seen that this dotted line is concave to the right and would doubtless become a (length)1/2 curve at a boat length of 9 or 10 metres (32.5 feet) - ballasted monohulls of course.

The causes of the fact that these boats do not obey the speed to square root law are as follows: a. Waves slow small boats. b. The small boats with a crew of two are relatively heavy. With a crew of one, as with the Laser, the position on the graph is actually above the root length line.

3. Hard chine boats, the Fireball is an example, seem just as fast as those with a round bilge. Clarence Farrar once told me that the best shape for an International 14 foot dinghy would be to have a round bilge forward and chines aft, if the rules allowed it.

4. The Una rig with no jib seems faster than the sloop. 8 out of 34 of the faster boats have it. It works best either with a pocket luff sail as in the Laser or a rotating mast, as in the Finn.

5. There are only two fully battened sails in the study, the Hornet and the Toy. The Hornet is a good average with its sloop rig. The Toy is among the fastest boats for its length.

6. Spinnakers do not add visibly to speed. I believe that someone has reckoned on them adding 4%.

7. The trapeze or sliding seat seems very valuable on the graph.

8. Keel boats and the heavy dinghy, the 22 sq.metre Sharpie seem to be fast. They show up rather well. The Tempest is better than the Flying Fifteen or Squib.

9. The Shearwater catamaran is plotted. It comes out to be faster than any other boat except the Australian 18 foot skiff. It owes its speed to its great stability, its low weight and low wetted surface which is less than that of a Firefly dinghy. The fineness of the hulls allows them to slice through the waves without losing too much speed.

THE SPEED Vs BRUCE NUMBER GRAPH

As with the speed to (length)1/2 graph, the reciprocals of the Portsmouth Yardstick numbers are graphed against the Bruce numbers of many boats.

This graph shows far less scatter than the previous one, thus showing it to be a superior speed estimator. Purely by coincidence, the Bruce number gives approximately the boat speed to true wind speed ratio on a free wind course. This will be studied later.

Most of the inferences which we saw in relation to the speed to (length)1/2 curve still stand out. However, the ballasted keel yachts, though conforming to the formula, sail much faster for their Bruce numbers than the dinghies. The reasons for this are as follows :-

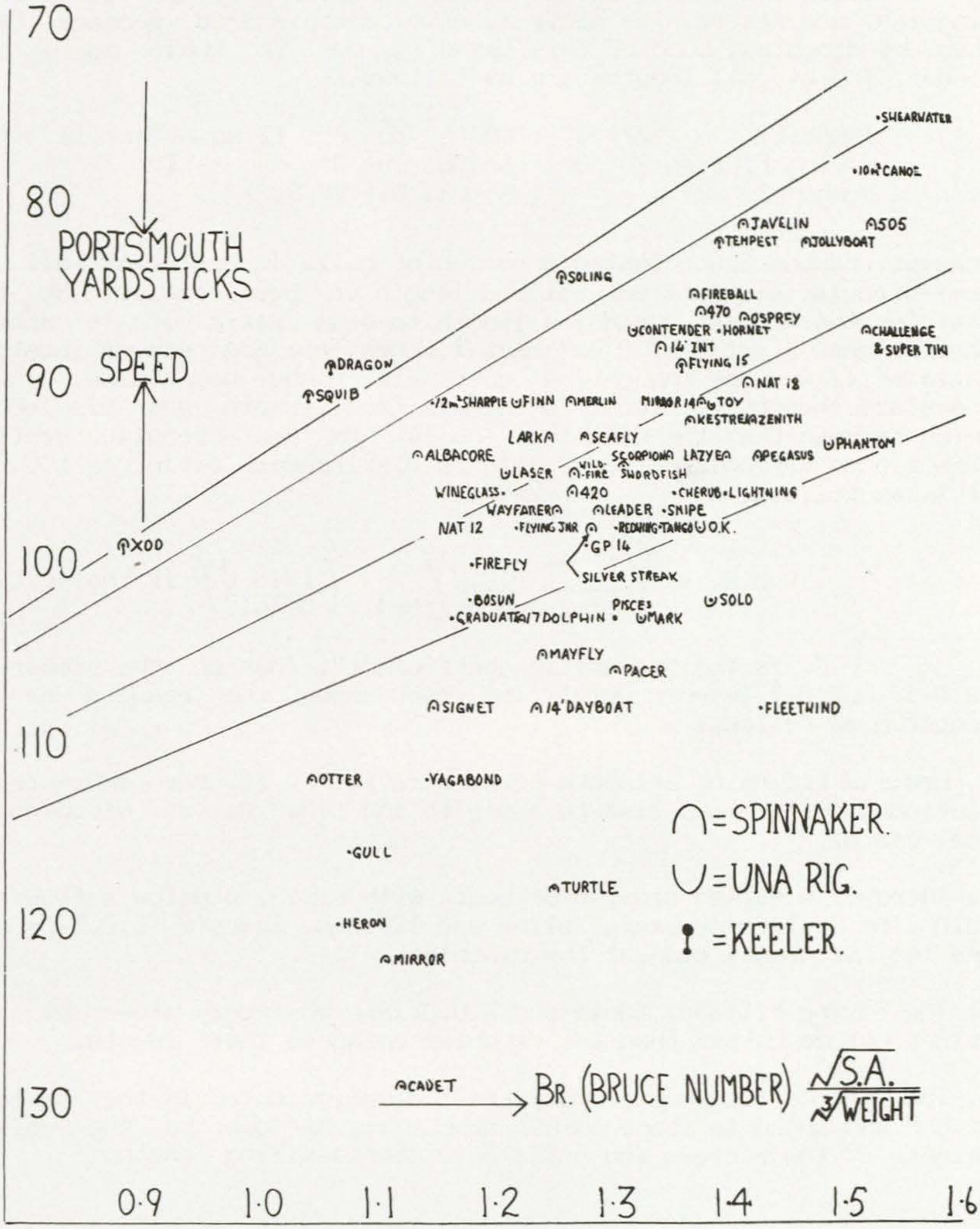
Up to a speed of 0.7 of the "waterline length speed" which is a speed in knots of the square root of the waterline length, in feet, almost the total resistance of a yacht is derived from the surface friction, wave making being minimal. Extra weight can therefore be carried with only a slight increase in resistance at slower speeds. One has to assume that most of their racing is carried out in lightish winds. The extra weight, however, reduces the Bruce number considerably. The keel yachts graphed here are the X.O.D., Squib, Dragon, Soling and Tempest. The heavy dinghy, the 22 Sq. metre Sharpie is similar. The Australians sail a "Light weight Sharpie" whose Yardstick number is 81, as compared to the heavy version which is 91.

Fifteen boats are slower than expected to make them fall well below the spread of the main mass of craft. They are : Mirror, Heron, Turtle, Gull, Vagabond, Otter, Signet, 14 foot Dayboat, Fleetwind, Pacer, Mayfly, Mark, Dolphin, Pisces and Solo. Their lengths vary from 8ft 8ins for the Turtle to 13ft 10ins for the 14ft Dayboat. 12 of them however are between 11ft and 12ft 5ins. Many of these lengths are nicely within the main clump of boats on the graph. One must think that some of the reasons for the poor performance of the above 15 as follows:

1. Too much windage from high topsides.
2. Too much beam.

3. They are 'knockabout' boats not raced keenly. The same boats are within the poor performance part of the speed to the square root of length graph.

THE SPEED Vs BRUCE NUMBER GRAPH



THE BALLASTED MONOHULLS

In the speed to the Bruce number graph, the surprise is again the relatively high speed of the ballasted monohulls. The Tempest and Flying Fifteen are well up with the fastest dinghies but the XOD, Squib, Dragon and Soling lie on a line of their own, well clear of the dinghies, and faster. The heavy 12 sq.m. Sharpie also appears faster than the dinghies. Much of this speed is due to these boats being longer. The overall lengths are as follows :-

Tempest	22' 0"	XOD	20' 8"	12 sq.m.Sharpie	
Flying Fifteen	20' 0"	Squib	19' 0"		19' 7"
Dragon	29' 2"	Soling	26' 9" 5		

However, Edmond Bruce tested a series of hulls in his tank all with semi-circular sections but various length to beam ratios. He found that for the highest speeds, a length to beam ratio of 16 appeared best whereas a ratio of 8 was best for heavier and slower boats. A ratio of 12 was, he thought, a good all round compromise. It was therefore thought to produce a formula from length and displacement which assumed that the dinghies' hulls had semi-circular sections. This figure was called the "Length to displacement ratio" or L.D.R. It it is as follows:

$$\text{L.D.R.} = \left(\frac{8\,\pi\ \text{P.C.}\,L^3}{\text{Displacement (Lbs)}}\right)^{\frac{1}{2}} = \left(\frac{17.6\ L^3}{\text{Displ.}}\right)^{\frac{1}{2}}, \text{ if the P.C. is 0.7}$$

P.C. is the "prismatic coefficient". That of the Shearwater is 0.85 but 0.7 is more usual. The graph shows the results of this research as follows:

1. Bruce's figure of a length to beam ratio of 12 for semi-circular sectioned hulls seems also to apply to the L.D. R. of dinghies and keel boats.

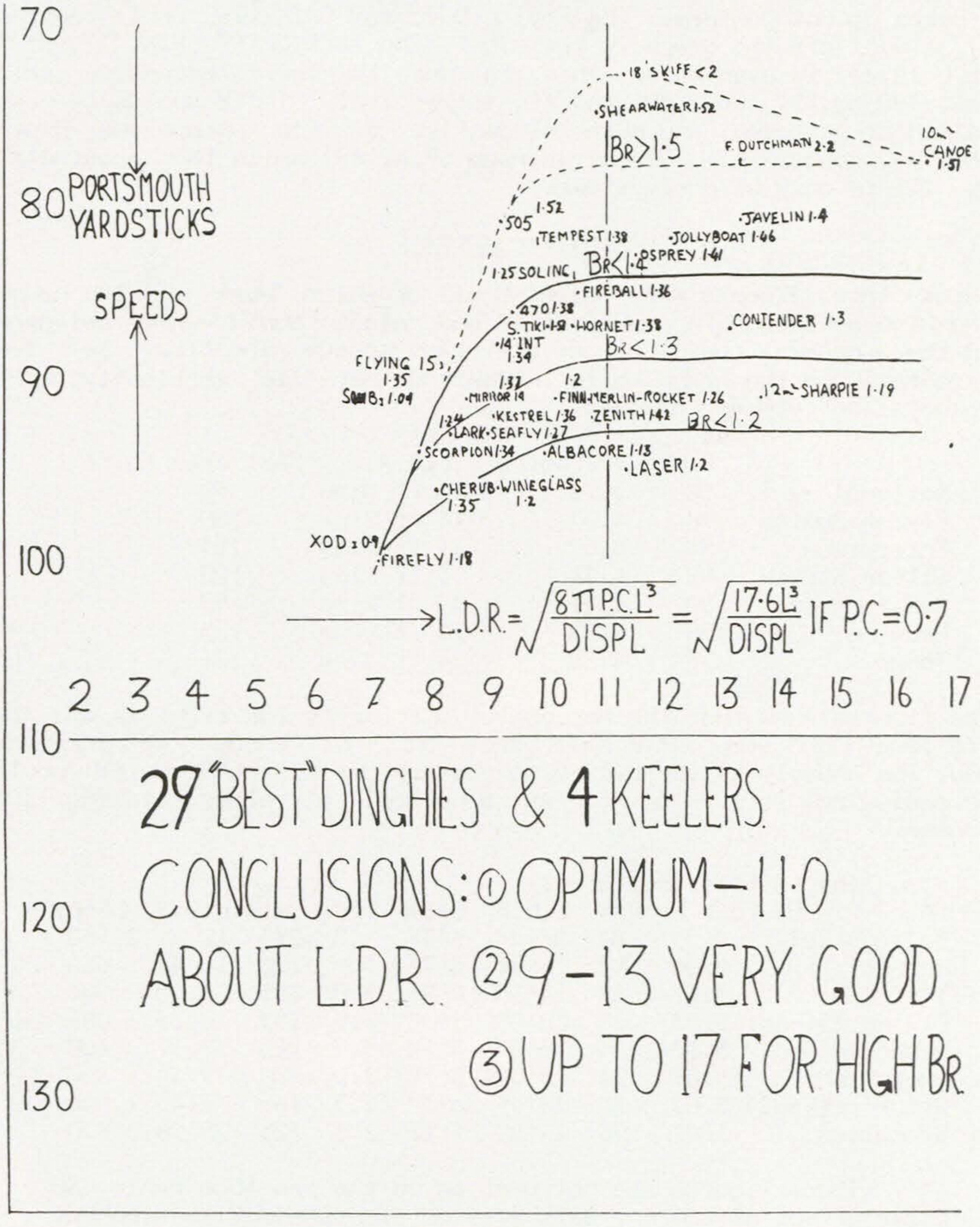
2. There is a marked slowing of boats with L.D.R.'s below a figure of 10.0 .The keelers Tempest, Soling and 12 sq.m. Sharpie (L.D.R.'s of 10 and 14) fit nicely amongst the dinghies.

3. The Flying Fifteen, Squib and X.O.D. are obviously slowed by their weight but do better than the dinghies owing to their length.

4. The poor performance of many small dinghies noted in the speed to length and speed to Bruce number graphs may be due to the relative weights of their crews and hulls on a short sailing length.

COMBINING THE $(L)^{1/2}$, BRUCE No. AND L.D.R.

The L.D.R. graph seems to make the heavier monohulls and small dinghies come into a better relationship with the racing dinghies. Some thought has been given to combining all these figures into a single graph. No formula has been seen which would do this.



THE BRUCE NUMBER X SQUARE ROOT OF LENGTH.

The graph show 77 sailing boats' speeds graphed against (1/2)the Br X (L).. It accommodates seven ballasted monohulls, six catamarans and sixty four dinghies. This graph is clearly better than the two previous ones. There is less scatter.

Two boats do not conform.. The Flying Dutchman (P.N. 78, Br X root L 9.7) is well off the graph to the right. The 18ft Skiff (P.N. 73, Br X root L 18.23) is even worse. This is due to their excessive sail areas, 390 sq.ft. and 1,600 sq. ft. respectively. Their speeds can be equalled or bettered, and more elegantly, by the catamarans Hydra (P.N. 73), Condor (P.N. 71) or Tornado (P.N. 69) while the Shearwater (P.N. 75) is only slightly slower.

THE SCATTER.

To study this, 7 boats were selected all of which were of the same speed with a Portsmouth number of 98 and eight boats were selected with the same Br X root L but of different speeds. The first set lie horizontally on the graph while the second set lie vertically. The horizontal set are as follows:

	P.N.	Br.root L	L.O.A.	Sail Area Sq.ft
National 12	98	3.98	12 ft 0ins	90
Flying Junior	98	4.37	12 ft 2ins	100
Enterprise	98	4.57	13 ft 3ins	113
Silver Streak	98	4.78	13 ft 6ins	120
O.K.(una rig)	98	4.81	13 ft 2ins	90
Redwing	98	4.87	14 ft 0ins	125
Tango	98	4.88	14 ft 8ins	121

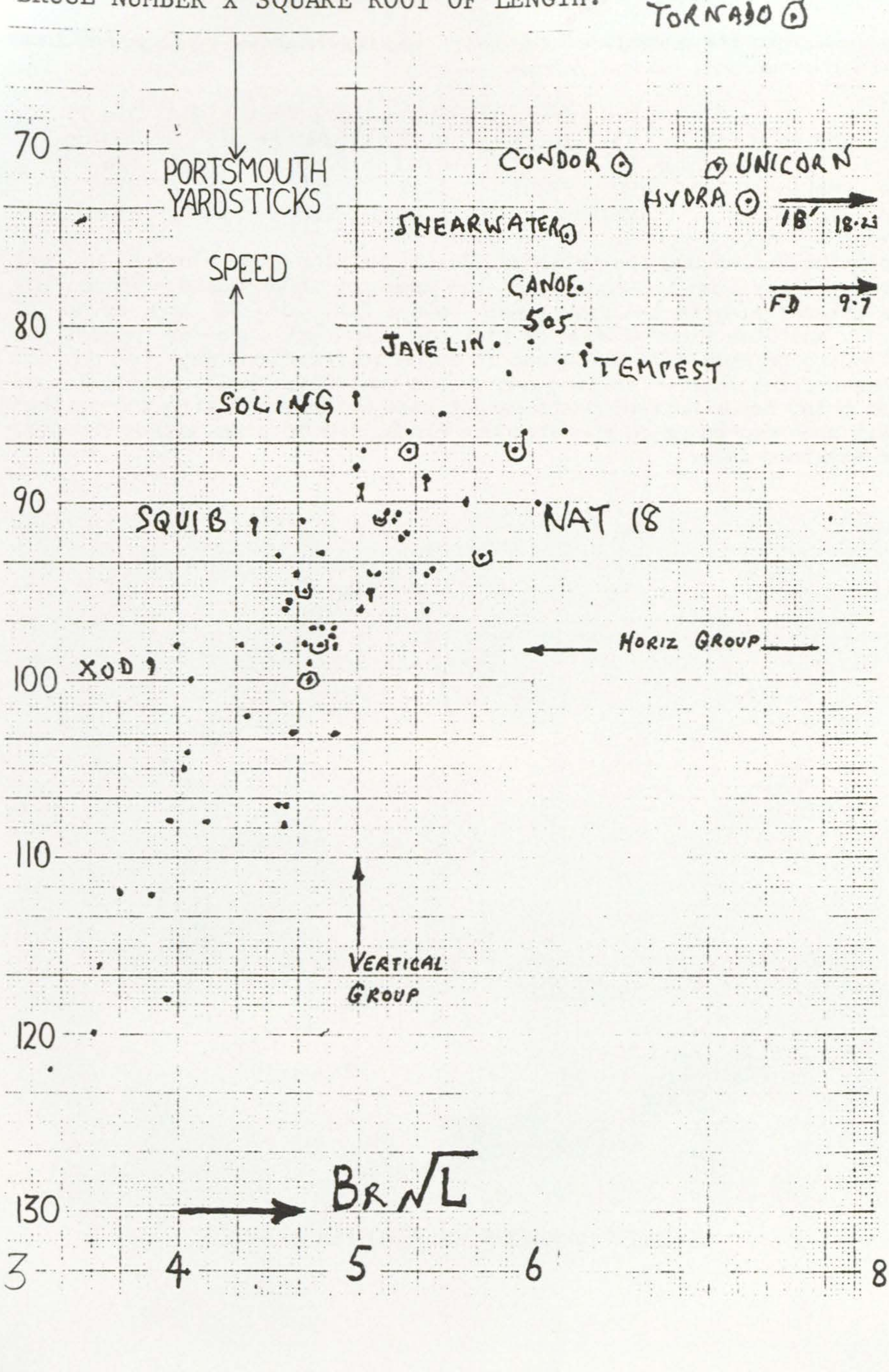
These figures show that the horizontal scatter to the right is due to extra length and some extra sail area but not enough to increase speed. The anomaly is the O.K. dinghy whose Una rig of 90 sq.ft. would seem equivalent to 122 sq.ft. as a sloop, a rather amazing 30% increase.

The vertical set are :-

	Br root L	P.N.	L.O.A	Beam	L/B	Sail	L.D.R.	Disp
Soling(keel)	4.99	84	26'9"	6'3"	4.3	235	10.4	2,560
Hornet	5.04	87	16'0"	4'7"	3.5	121	10.4	660
14ft Int.	5.0	88	14'0"	4'8"	3.0	125	9.08	585
Flying 15(keel)	5.03	89	20'0"	5'0"	4.0	153	8.13	1,085
Albacore	5.13	94	15'0"	4'1"	3.7	125	9.9	600
Swordfish	5.07	94	15'0"	5'1"	3.0	130	9.5	660
Wildfire(keel)	5.07	95	16'9"	6'3"	2.7	165	8.4	1,040
Wineglass	5.01	96	15'0"	5'10	2.6	123	8.98	600

These figures are not neat as in the previous table. No clear effect of L.O.A., sail area or displacement is seen but the faster boats have less relative beam than the slower ones and tend to have a higher L.D.R. which shows the value of that figure.

BRUCE NUMBER X SQUARE ROOT OF LENGTH.



THE SKIFF, DUTCHMAN, NATIONAL EIGHTEEN AND VULCAN

To look into the anomaly of the Skiff and Dutchman,we can compare them with the National 18 and Vulcan.

	P.N.	Br root L	Br.No.	Sail Area	L.O.A.	Displ.
18 ft Skiff	73	18.23	4.32	1,200 ft	17' 9"	790lbs
Flying Dutchman	78	9.70	2.20	380	19'10"	724
National 18	90	6.03	1.42	190	18' 0"	910
Vulcan	90	5.6	1.42	150	16' 8"	640

Both the Vulcan and the National 18 lie within the scatter of our graph. The Vulcan lies nearly on the mean of the boats, while the 'eighteen' lies to the right. Both have a P.N. of 90 and Br.No of 1.42. What the figures show is that one can get greater speeds by slapping on huge sail areas but it is an ineffficient way to do so. However, the 'hairy' sailing and speeds must have their appeal. To pay for this, 'over-hatted' boats cannot race while boats with the optimum sail area can do so in the stronger winds. The optimum sail area will be examined later.

'SYDNEY HARBOUR SKIFF AT FULL SPEED'

THE BALLASTED MONOHULLS

There are seven ballasted monohulls on the graph. Four fit excellently into the mass of dinghies while three, Soling, Squib and X.O.D. are on the fringe of them at the favourable side i.e. they sail faster than the dinghies of the same Br. X root L. The table is as follows :-

	P.N.	Br X root L	Br.No.	Sail Area	L.O.A.	Displ.
Tempest	82	6.29	1.39	247 sq.ft.	22' 0"	1,460lbs
Soling	84	4.99	1.12	233	26' 9"	2,560
Dragon	89	5.38	1.057	286	29' 2"	4,100
Flying 15	89	5.03	1.20	153	20' 0"	1,085
Squib	91	4.41	1.01	173	19' 0"	1,860
Wildfire	95	5.07	1.27	165	16' 9"	1,040
X.O.D.	97	3.84	0.91	184	20' 8"	3,360

The reason for the good performance of the Soling, Squib and X.O.D. is now apparent. They have a small rated sail area which shows up in the Bruce number. The Dragon also has a small rated sail area but her greater length puts her amongst the dinghies. In practice, 'drifters' and light wind sails will increase the speeds.

THE CATAMARANS

Six catamarans are plotted. Five of them fit well on the line of the dinghies. The Unicorn and Hydra are to the right and one suspects that they have too much sail area. The table is as follows :-

	P.N.	Br.root L.	Br.No.	Sail Area	L.O.A.	Displ.
Tornado	63	7.50	1.72	220 sq.ft.	20' 0"	640 lbs
Condor	71	6.51	1.63	183	16' 4"	570
Unicorn	71	7.07	1.69	150	18' 0"	560
Hydra	73	7.24	1.80	210	16' 6"	425
Shearwater	75	6.19	1.52	165	16' 6"	615
Swift	87	5.31	1.39	140	14' 6"	611
Aquacat	100	4.72	1.35	90	12' 2"	525

The sail area of the Shearwater is taken to be 165. Rhonda Budd gives it as 235 sq.ft. which is that of the Shearwater IV. It will be seen from the Bruce numbers that the Hydra has indeed got too much sail area. Unicorn has more sail area than desirable. Moreover, it is in a Una rig. One would have expected a lower Portsmouth number.

CONCLUSIONS.

1. The formula Bruce number X (L) -bears a sensitive and delicate relationship to the speeds of dinghies, ballasted keel boats and catamarans.
2. If Br. root L is used as a rating formula, it will encourage smaller sail areas of greater efficiency. It will also encourage an L.D.R. of 11.0 or 12.0.

DESIGN FOR FAST SAILING

The graphs which we show clearly indicate what gives sailing speed. The four factors are :-

1. Sail Area. The amount which can be carried depends on the stability. This can be increased by a trapeze or sliding seat with marked advantage. As far as the hull goes, one can place types of boat in order of stability thus :- a. The catamaran. b. The trimaran. c. The scow. d. The flat floored New Haven sharpie. e. The beamy round bilged dinghy. f. The semi-circular sectioned hull. The scow and New Haven Sharpie are both very fast but pound forward in a seaway. They have not been favoured in Europe since the "swim-headed" Thames barge of the early 19th century. On the U.S.A. East coast where the winds are light, dories are used.

2. Light displacement and the lighter, the faster.

3. The Length to Displacement ratio, the L.D.R., is a great hindrance to speed if it is below a figure of 11.0 or 12.0. Higher ratios increase speed by having a smaller wetted surface.

4. Length increases speed. In the test tank, it is always shown that the resistance is proportional to the square of the speed although this depends on the length and smoothness of the hull. For very smooth hulls, it can be as low as an index of 1.8, instead of 2.0. This means that the speed is proportional to the square root of the resistance or driving force. This proportionality only persists until the hull begins to make waves when the resistance becomes greater. This occurs at the figure of 0.7 of the square root of the waterline length, in feet.

In our graphs, using the Portsmouth Yardstick numbers, speed is proportional to the square root of the sail area. This means that the figures of comparative speeds when sailing in races have been taken in the lighter winds when the boats are moving below the 0.7 of the square root of the waterline length. However, even then, wave-making resistance must exist. Otherwise the slimness of the hull, as given by the L.D.R. would not have any effect.

OPTIMUM YACHTS

We have now concluded our study of what makes for speed in yachts. We have also found that all yachts, whether dinghies,keel boats or catamarans, conform to the same rules and can be compared to each other. This allows us to compute the relative speeds of all yachts in terms of the Portsmouth number by using the length, displacement and sail area.

We are now ready to study optimum yachts in terms of:

1. Speed to windward	2 Speed to cost ratio
3. Speed to 'home base'ratio	4 Speed to sail area ratio
5. Speed to length ratio	6 Speed to displacement ratio
7. Speed to accommodation ratio	8 Speed to seakindliness ratio
9. Speed to true windspeed ratio	10 Speed in very light winds.

THE CLOSE HAULED SPEED.

The factors which give speed to windward are as follows

1. A high value of Bruce number X root "length".

2. A high value for the L.D.R. (Length to displacement ratio). It should be at least 11.0 and higher values are faster.

3. An optimum sail area which is the length multiplied by the beam and a factor which is about 1.5 for dinghies but decreases for faster boats to become 0.85 for the fastest multihulls.

4. A high aspect ratio, fully battened Una rig with a bendy plank mast to take the twist out of the sail. The mast must twist to avoid turbulating the wind on the lee side of the sail. With ice yachts, high aspect ratio is more important than sail area within reasonable tolerances.

5. The sail should come as low to the deck as possible to minimise the boom eddy. The cabin top can be built to lie just below the boom.

6. The boat herself should be as streamlined as possible to minimise wind resistance.

7. The most efficient centreboard or fixed keel which should have an aspect ratio of 1.0 in terms of span /Area, a profile like the wing of a supersonic aeroplane and an area which Edmond Bruce gives as:

SPEED TO WINDWARD OPTIMUM YACHTS

Yachts will, on average, spend one quarter of the distance they travel close hauled. This is because they seldom sail at a best Vmg (speed directly to windward) at a course less than 45 degrees from the true wind direction. In terms of the time spent sailing, nearly half of the time is spent close hauled because speeds close hauled are much less than when the wind is free.

Because of the time spent sailing to windward in races, the Portsmouth number of a yacht is a good index of its windward ability. For this reason, it might not be thought necessary to devote a section of this writing to windward ability. However, windward ability is essential in the Trans-Atlantic races from England to America and it may not be the optimum.

WINDWARD ABILITY YACHTS.

These can be divided into three groups:-

1. The 'All keel' yachts such as the Bermuda sloop, the 'Plank on edge' English cutter of the 19th century which was fast on all courses but sailed heeled a great amount and Dorade, designed by Rod Stephens and described in Uffa Fox' "Sailing, Seamanship and Yacht Construction". This last won the Fastnet race.

2. The 12 Metre yachts whose keels are shaped like the wing of a supersonic aeroplane.

3. Very fast yachts such as the faster multihulls and ice yachts which, due to their speed, sail with the apparent wind up to 8 degrees from the bow at least, even when the true wind is aft of the beam.

$$\frac{\text{Sail area}}{\text{Board area}} = 257 \left(\frac{Vb}{Va}\right)^2$$

Where Vb is the boat's speed and Va is the apparent wind's speed.

The general theory of sailing and its inferences for optimum yacht design are to be found in the A.Y.R.S. book "Design for Fast Sailing" by Edmond Bruce and Harry Morss. Moreover, the mathematics needed to understand it are not great.

For optimum windward sailing, it helps to know the "Course Theorem". This states :- On any heading, the Beta angle (course made good to the apparent wind) is the sum of a) 'drag angle' of the sails and hull windage in the wind and b) the 'drag angle' of the centreboard or keel and the hull in the water.

The course theorem implies that the 'Theoretical Yacht' consists only of a sail in the air and a centreboard in the water, with no hull at all. This, in turn, means that any hull interposed between the sail and the centreboard will increase the drag angles of both sail and centreboard. This will result in a higher minimum Beta angle and a lesser ability to sail close to the wind.

"PINCHING"

This is sailing closer to the wind than the course which will give the best Vmg or velocity made good directly to windward. There is some controversy as to what happens. I think it is as follows :-

At the best Vmg, the boat is sailing at the minimum sum of the two drag angles. When one sails closer to the wind, the drag angles increase. The boat then slows which frees the apparent wind direction and keeps the drag angles at their minimum. When this no longer works, as the boat is headed up, it simply stops. The ice yacht (or the 'theoretical'yacht as above) may show the picture better.

The ice yacht always seems to sail with the sheet pinned in, no matter what the course. The sail drag angle is thus always at its minimum and, of course, the drag angle of the runners on the ice is negligible. When sailing free or tacking down wind, the ice yacht speeds up to make Beta equal to the sum of the drag angles. When sailing to windward the yacht slows down to achieve the same purpose. When 'pinched' it has been slowed too much.

Another concept which may be valid is that, when a yacht is sailing 'pinched', it is sailing as a "theoretical yacht",as above. The Beta angle is then the sum of the drag angles of the sails and centreboard or keel. But, the windage and water resistance of the hull are fighting the otherwise excellent performance of the "theoretical yacht". Certainly, when one is trying to keep a 'pinched' yacht sailing, one seems to be balancing two opposing sets of forces.

OPTIMUM DRAG ANGLES

The wings of aeroplanes are largely assessed in terms of the "lift to drag" ratio. This is because what is wanted is lift and the resulting drag has to be overcome by the thrust created by the power plant. This is a simple matter compared to the performance of a sailing boat where the speed, though still hindered by wind and water drag, depends on angular relationships. For this reason, I prefer to use the "drag angles" instead of lift to drag ratios. The two are essentially the same thing, the drag angle being the angle whose Cotangent is the lift to drag ratio. A small drag angle has a high lift to drag ratio. A large one has a low lift to drag ratio.

One can thus assess a yacht's performance in terms of the drag angles of the sails and hull windage and the centreboard and hull's combined force. This is especially important in windward performance.

At one time, the A.Y.R.S. had a yacht wind tunnel of 8 foot by 8 foot square section. It was before its time and not used. It has now disintegrated but I did take one figure from it which was the drag angle of a model dinghy and sails, beautifully made by Ruth Evans. The close hauled drag angle was no less than 15 degrees which gives a lift to drag ratio of 3.7, an atrocious figure for an aerofoil. Edmond Bruce has however, confirmed such figures by his various tests. The figures quoted below are his.

Drag angle of single 'pocket luff' sail with no battens and a loose foot : 8 degrees (L/D 7.1)
Drag angle of above sail on an open dinghy,with crew: 17.35 degrees (L/D 3.2).
Minimum course to the apparent wind : 33.3 degrees

COMMENTS

The drag angle of the sail could be reduced by having battens right across the sail, a turning mast and abolishing the boom eddy. I guess at a figure of 5 degrees.

The hull windage is obviously the cause of the dinghy's poor figures. It could be reduced by having as low a freeboard as possible; putting a deck on the dinghy and rounding the sections at the gunwales. This is partially achieved in the Laser and Fireball dinghies and fully used in the sailboards. I guess at a figure for the sailboard of about 10 degrees.

The hull drag angle of the above dinghy cannot be altered by design. The hull drag angle of a catamaran is, however, 13.1 degrees (L/D 4.3) an improvement of about 3 degrees. Perhaps these 3 degrees account for the superior performance.

OPTIMUM LEEWAY ANGLE

Edmond Bruce gives this as between 4 and 6 degrees. If it is less than 4 degrees, there is too much lateral resistance. If more than 5 degrees there is too little.

OPTIMUM CENTREBOARD ASPECT RATIO

From tank tests on the aspect ratios of rudders in U.S. naval ships, Edmond Bruce states that the optimum aspect 2 ratio for a centreboard or keel is 1.0 in terms of Span /area..an This low figure is due to the fact that a centreboard or keel makes surface waves, positive on the lee side, negative to weather. The longer such waves are, the less the resistance. This explains how the low aspect ratio keels which are used on several catamarans and trimarans work.

There is some rather weak evidence that the optimum centreboard is twice as long at the hull as it is in depth. The 12 metre keel which is like the wing of a super-sonic aeroplane is, presumably, an optimum. It could be that the optimum profile of a centreboard should be similar.

THE DART AND EDEL CATAMARANS.

These designs are roughly similar. The Edel catamarans are French. The concept is to have deeper sections in the fore 2/3rd of the hull and the keel profile slopes down aft. The fore 2/3rds of the boat then acts like a low aspect ratio keel and provides adequate lateral resistance. Aft of this, in the remaining 1/3 rd of the boat, the hull sections are rounded. The hulls are symmetrical. No centreboards are used.

Both of these catamarans are fast but I do not know how they compare with the usual designs.

THE UNA RIG

In view of the apparent 30% of extra sail efficiency shown by the dinghy with the Una rig, research into this rig was needed.

Sailing Boats of the World gives sixteen dinghies with the rig. The ratio of sail area to length multiplied by beam varied between 1.06 for the Moth to 1.7 for the Arrow, as compared with the apparent optimum of 1.6. The average of the sixteen dinghies is, however, 1.38 which indicates that 86% of the sail area in a Una rig is as fast as the sloop rig around a racing course. This is unflattering to the sloop rig but many of the Una rigs were not the optimum, which would make the comparison worse.

The rules for the Una rig are as follows :-

1. The mast must rotate to prevent it turbulating the windflow on the lee side of the sail. Ice yachts use a plank mast which bends with the hollow to windward to take some of the twist out of the sail.

2. The sail must be fully battened to give a flow of 1 in at least 8. Rod MacAlpine-Downie once used a flow of 1 in 6 in an early C class catamaran in "Little Americas Cup" race - and won.

3. The luff to foot ratio should be about 3 to 1 but this depends partly on the size of the boom eddy. A ratio of 4 to 1 would be theoretically better.

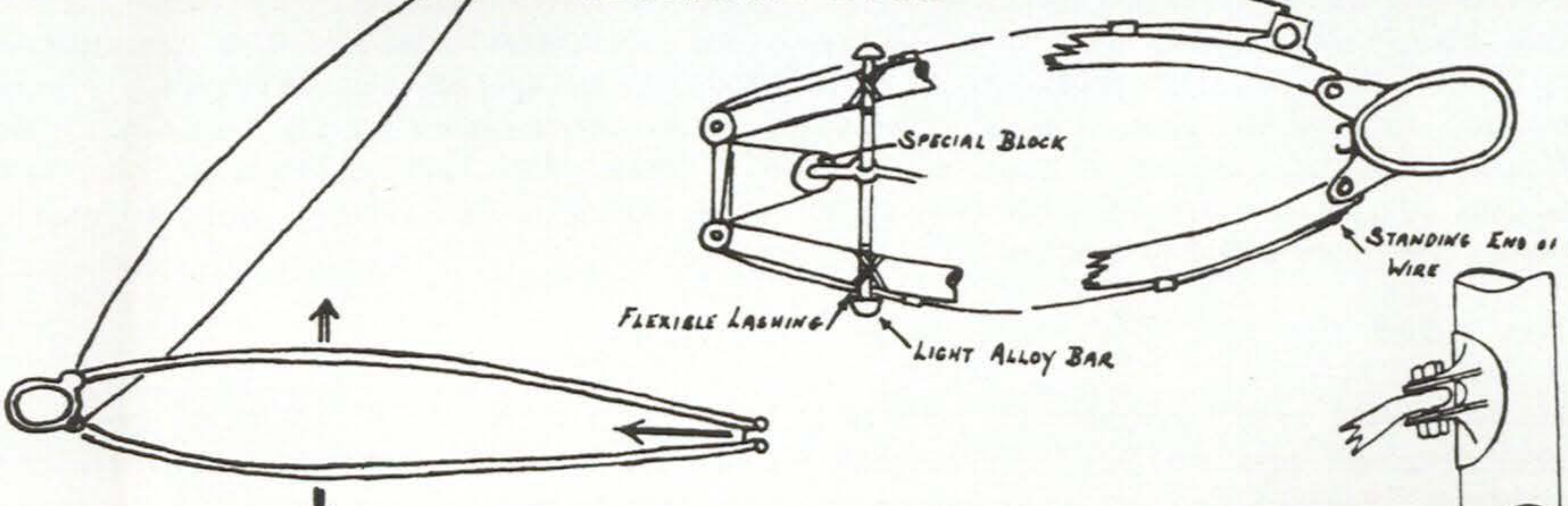
4. The boom eddy should be blocked as far as possible either by bringing the sail down to the deck or trampoline or to built up coamings or a cabin top which should be of the close-hauled aerofoil shape. This will interfere with the boom downhaul (kicking strap).

5. A wishbone boom can be used, set part way up the mast. This abolishes the need for a boom downhaul, allows the foot of the sail to sweep the deck or cabin top and gives flow to the foot of the sail. It,in turn, interferes with reefing.

CONCLUSIONS.

1. The sail coefficient is probably more than 2.0, as compared with 1.2 for the sloop.
2. The sail drag angle is reduced.
3. The speed to windward is probably doubled in light winds.
4. The reaching speed is probably not worse.
5. The speed on a dead run is greater.
6. The sail area will be much less. Drifters and spinnakers should not be of much use to a fast yacht when she is tacking down wind at a course of 135 degrees to the wind. The sail coefficient of the total sail area will be reduced to 1.1 or less.
7. A wishbone will reduce the strain on the sheet.
8. There will be no foredeck sail changing
9. The only sail which can touch the Una rig is the high aspect ratio, fully battened semi-elliptical squaresail. But the art of small square rigged seamanship has been lost.

WISHBONE BOOM



A GUNTER LUG UNA RIG

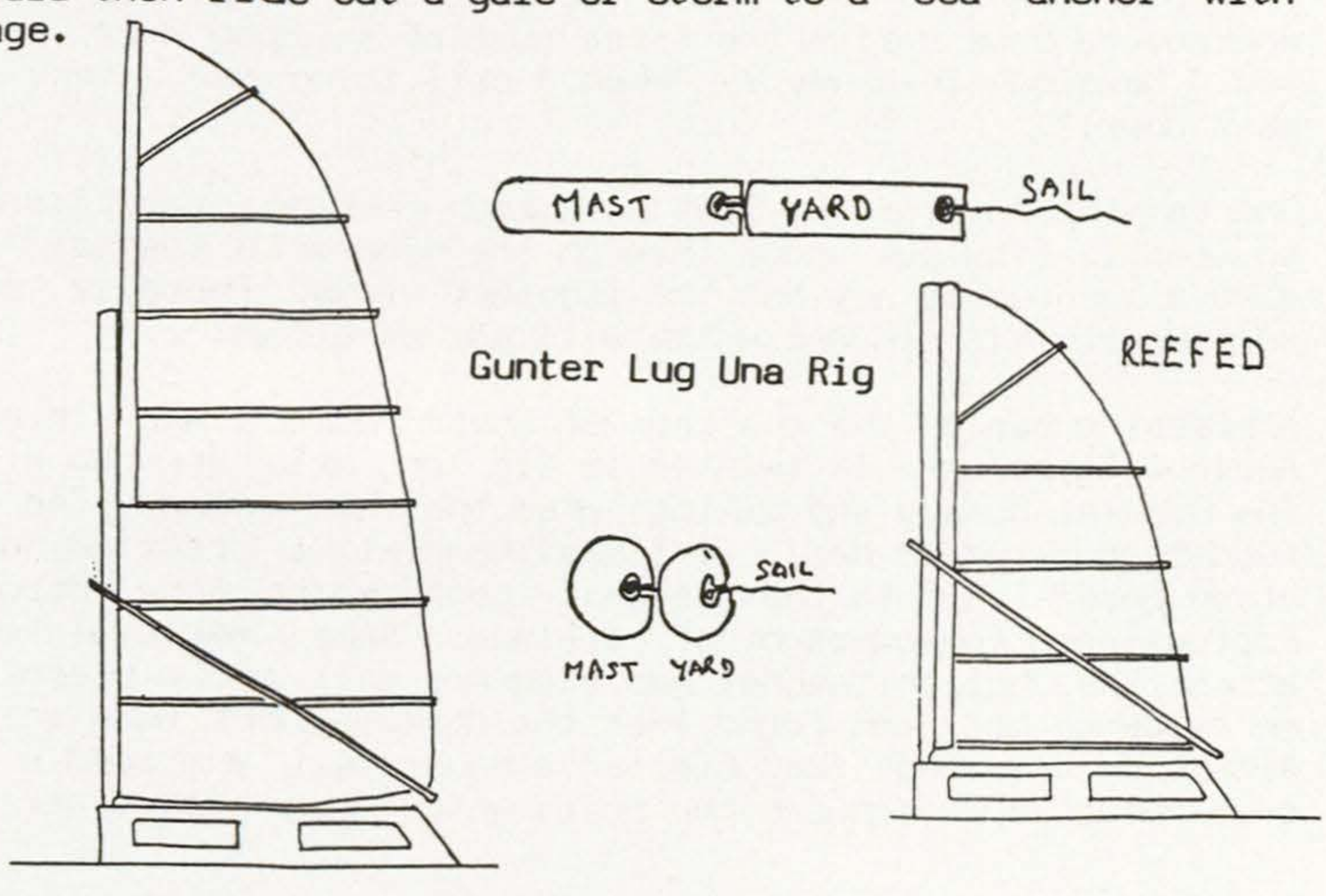
In the 1920's and 1930's, the Bermudian rig ousted the gaff rig because of its better performance to windward. One of the complaints against it was that the mast could not be reefed with the sail but stuck up bare in gales at sea. We are now so used to the rig with light alloy masts and better staying that the bare mast in gales is no longer thought about.

In the previous writing, it is now suggested that the optimum rig for a very fast yacht such as a multihull is a Una rig of aspect ratio with a luff to foot ratio of 3:1 or even 4:1. Also, in line with ice yacht experience, one would want a bendy plank mast (which could be made of light alloy). The combination would lead to a boat with a lot of windage with no sail set. The early Shearwater catamarans used plank masts and one at least tipped over while sitting on the beach with no sail set in a gale. As a result of this, and for lightness, modern Shearwaters use a round mast which can turn to abolish the turbulence on the lee side of the sail. It appears to be just as good as the plank mast.

The suggestion of this article is that the gunter lugsail could be of use to reduce the mast height with the sail area. The yard would be an alloy extrusion with an elongated bulb-shaped excrescence at the leading edge and luff groove for the sail, aft. It could then slide up and down in the luff groove of the mast, taking the sail with it.

For efficiency, both the mast and yard would have to turn together. With round poles, this would need some clever sail cutting at the foot of the yard. The idea is therefore drawn with plank mast and yard.

The last piece of this suggestion is to have the mast and yard capable of being lowered at sea when they would not stick out far over the stern. One could then ride out a gale or storm to a sea anchor with minimal windage.



Gunter Lug Una Rig

SMALL SQUARE RIGGED SEAMANSHIP

In the previous writing, we have noted that the art of square rigged seamanship has been lost. We have also noted that the squaresail has advantages in regard to efficiency. To this, we may add the value that several deep sea sailors such as Weston Martyr ("Southseaman") and Irving Johnson ("Yankee") give it. It is therefore worth while to study boats and ships with a single squaresail to see if we can resurrect the seamanship.

The two great faults of the squaresail are a) that one can be caught aback and b) that the sail or sails are aback when putting about through the wind. This stops the boat. The risk of being caught aback is not great with careful steering. For instance, Tim Severin's "Brendan", a curragh with which he crossed the North Atlantic, was only caught aback once and that was in the ice. The main fault happens when putting about. This could cause the Humber Keel, a large sailing barge with a squaresail, to make three lengths of a sternboard putting about when lightly laden.

Going right back to the beginning, we find that the squaresail was independently invented in Europe, Asia and Africa (Egypt). It was occasionally used in America in the North West and Lake Titicaca although a jib-headed triangular sail was also developed with a sprit across it like a sailboard sail. This was used in the Jacandra of South America on the East Coast. In the Pacific, they invented the Oceanic Lateen and the Lugsail (Sunda Islands).

Once sail had been developed in a boat which could carry it, one may be sure it was used. Rowing or paddling is tedious work. However, when working at their nets or laying lines, the sail and mast would be taken down and stowed in the boat. As a youth, I saw the last of the fishermen to use a sail on Lough Neagh. They used a spritsail which they took down and laid along the boat, both mast and sprit, when they worked. We thus derive the first rule of sailing ever produced. This would have run this way :- "When a sail is no use, take it and the mast down."

One can reason from the last paragraph that no primitive boat with a squaresail EVER put about through the wind with the sail set. It was always lowered in any but the lightest winds. There is much evidence to support this concept which will now be given.

A steering oar on the quarters of their boats was invented by the Ancient Egyptians. It twisted in its long axis and had a short tiller. The Greeks, Romans and Vikings used the same method. The stern central rudder appeared in Medieval times. However, a steering oar over the stern persisted into the present century in the Barco Rabelo of Portugal and the curragh of Ireland. Some medieval ships sailing across the English Channel had a square sail and a stern steering oar. No evidence had been found that the Anglo-Saxons used sail but it is almost certain that they erected a squaresail and used a steering oar over the stern. Although the boats which used the steering oar over the stern were either boats which sailed from beaches or in shallow water, I guess that they also lowered the sail when putting about and rowed the stern around for the new tack before hoisting it again.

The Roman ships which brought wheat from Egypt to Rome had a unique sail furling method. Lines ran up and down the sail in rings attached to it. By pulling these lines, the whole sail could quickly be pulled up to the yard. I think this was done every time the ship put about.

The dipping lugsail was invented in Brittany in the 18th century, as far as I can gather. It is better to windward than the gaff sail and may equal the Bermudian. The sail has no twist and a clean leading edge with no turbulating mast below the yard. It could only have been derived from the squaresail and not the standing lugsail which was confined to Venice and Adriatic waters. I see the invention as follows :- When lowering the sail to put about, the tack was left attached forward . The yard then became vertical and the whole sail and yard were pushed ahead of the mast on to the lee side. The sheet was then gathered in and the sail was ready for sailing. This was less work than switching the tack and clew as was necessary with the squaresail.

CONCLUSIONS.

Some evidence has been produced that small squaresails were lowered when putting about. The sail was furled in Roman ships.

AN OPTIMUM SQUARESAIL

An optimum squaresail must be very similar in shape to the Una rig which we have described. It must have a high aspect ratio, be fully battened - they will be called "yards", have a 'clean' leading edge and the foot must come as close to the deck as possible. It can, however, have two advantages over the Una rig; it can be twistless and it can have the theoretically optimum plan form of a semi-ellipse. It therefore is again worth re-considering despite the fact that A.Y.R.S. members who have made the sail found they could not sail with it in comfort and pleasure.

The two faults of the squaresails which have been made are:

1. When the sheets are eased, the sail goes more fore and aft. In the sail to be described, this is corrected by a length of shock cord leading forward from the centre of the 'boom' or yard at the bottom of the sail.

2. Because the sail is aback when head to wind, the boat will stop while putting about. This is avoided by lowering the sail before putting the helm down and hoisting it again when on the other tack.

THE SAIL

This is a semi-ellipse of $Hoist^2/Area$ of 3.0 or even 4.0 The flow is 1 in 8 or, if one wants to be daring, 1 in 6 produced by light alloy or stainless steel tube yards in pockets in the sail. To keep the flow up to the top of the sail, the upper, shorter yards will have less radius than the longer ones.

The sail is kept outside the shrouds by a sprit from the mast to the middle of the boom. Two parallel guide wires run from the boom to the ends of a horizontal pole at the masthead which is the length of the uppermost yard. Each yard has rings on it which encircle these wires. These wires will keep the sail under full control whenever it is being hoisted or lowered.

The halliard runs from a block at the masthead to a jam cleat in the midline near the helmsman. It thus acts as a backstay but, if let go, the sail will fall down to the boom, thus reefing the sail in the same way as the Chinese lugsail.

A length of shock cord and line runs from the middle of the boom around a block forward and back to the helmsman. Tension in this will make the boom go more athwartships when the sheet is eased. More tension would perhaps be needed in stronger winds.

Sheet loading will be small, being entirely the tension in the shock cord. A single line from the centre of the boom to the cockpit should be enough. From the cockpit, the line could then run back around the mast, again to be attached to the centre of the boom for the other tack.

SUMMARY

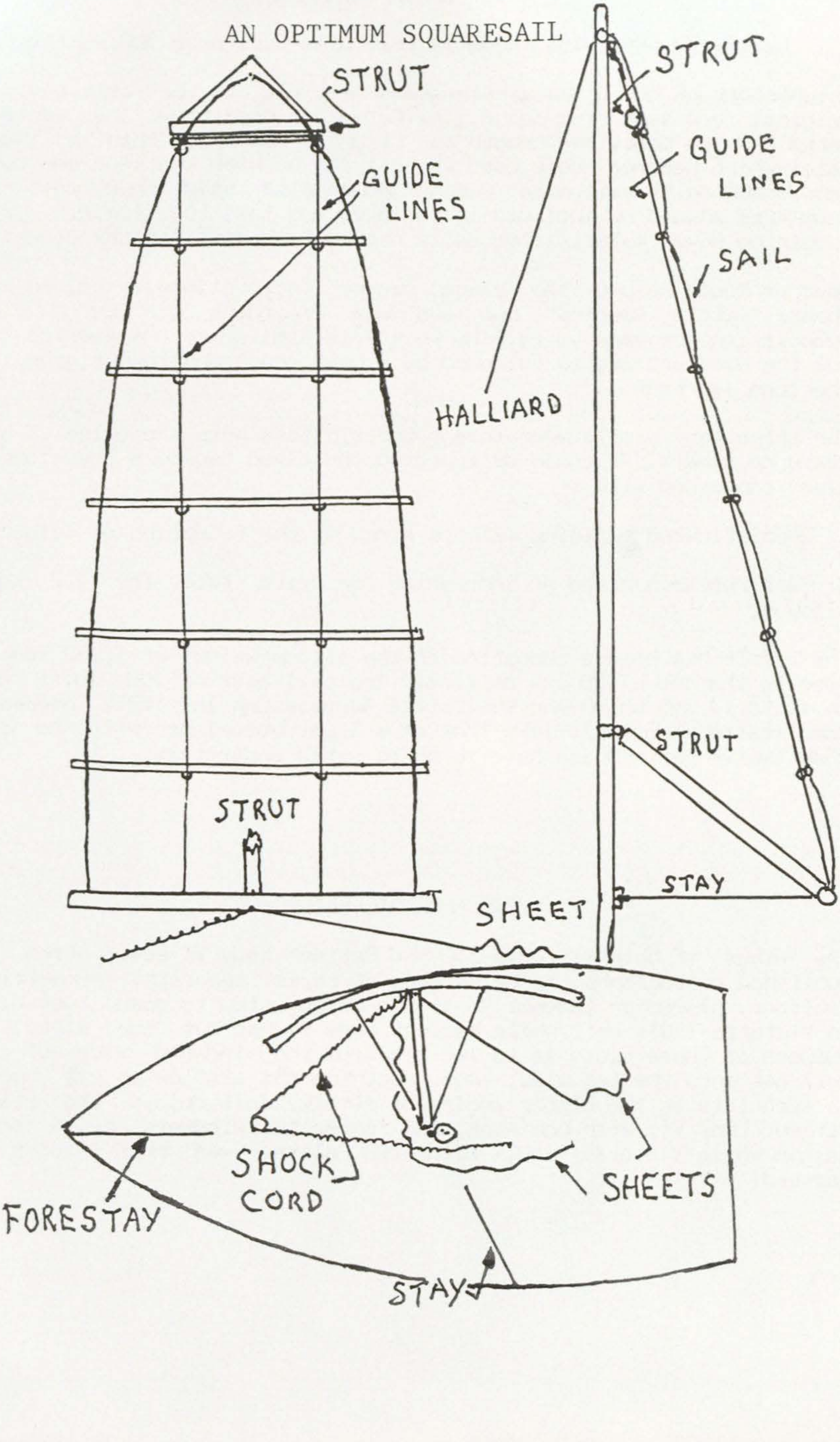
A squaresail is described which might just be tolerable. I made and sailed a version of it in 1950 and it went well. The advantages of it are :-

1. The most efficient sail possible
2. Reefing as in the Chinese junk sail.

The disadvantages are :-

1. The sail may have to be lowered when putting about in any strength of wind.
2. The danger of being 'caught aback'.
3. The mast has to be placed farther aft in the boat.

AN OPTIMUM SQUARESAIL



THE 'C' CLASS CATAMARANS

L.O.A. 25 feet 0ins Beam 14 feet 0ins Sail Area 300 sq ft.

The history of the C Class catamarans has yet to be written. The original idea came from the R.Y.A. Catamaran Committee. They wanted a large two man boat. The length is slightly shorter than a Thames Rater which Beecher Moore used to sail and he knew that two men could handle 300 sq.ft sail area. Beecher Moore also said that mast and boom area should be included in the area and that the I.Y.R.U. rule requiring woven material for sails need not be used for the class.

Beecher Moore helped the class become International, coined the phrase "Little America" cup and was President of the C class association for some years. The course is similar to the America Cup but the windward leg is followed by a beam reach and then a gybe for the long leg back.

The three very simple measurement restrictions were the rules. I have heard no others. As could be expected the class became a development class concerned with :-

1. Sophisticated building methods aimed at the reduction of weight.

2. Sail research aimed at increasing the drive from the 300 sq.ft allowed.

The result has been a reduction of the all up weight of 1,250 lbs or more to the 450 - 500 lbs of today. The sail area of 300 sq.ft has, in Victoria 150 which won the Little America Cup in 1985, become a complicated wing built like that of a light aeroplane with no less than twelve parts which have to be adjusted separately.

THE AEROFOIL SAILS

The 'wings' of both Victoria 150 and Patient Lady Vl seem, from the published photographs, to be made up of three separate, symmetrical sections, placed in tandem. These can be adjusted to open two slots in Victoria 150's sail while Patient Lady Vl has but one slot. The purpose of these slots is to let air from the windward side of the sail get onto the lee side, thus smoothing the airflow as it begins to turbulate at the higher angles of attack. This delays the stall. Patient Lady Vl, with one slot, was faster to windward by a small margin while Victoria 150, with two slots, was much faster to leeward.

HULL DESIGN AND CONSTRUCTION

In the early designs, Rod MacAlpine-Downie could use a short overhang forward and still win. Nowadays, the stems are vertical and draw a couple of inches to get the most value from waterline length. The forward V's develop into semi-circles amidships and these appear to flatten out a bit aft to give a transom approximately three quarters the width of the maximum beam. At rest, the transoms just 'kiss' the water. The topsides are vertical. Both Victoria 150 and Patient Lady Vl, the 1985 U.S.A. defender, had similar hulls of this type.

In hull construction, Victoria 150 is built of laminated plywood with reinforcement at the stress points by carbon fibre. The cross beams are aluminium alloy mast extrusions. Patient Lady Vl's hulls were honeycomb sandwich, the skins being carbon fibre and S-glass.

I do not know the research which went into Tony DiMauro's Patient Ladys but believe that there were wind tunnel tests. Lindsay Cunningham, who designed Victoria 150's wingsail has his own wind tunnel in which he can test 5 foot high models. The instrumentation is simple and exact windspeeds and forces are not taken. Mainly, the concentration is on the RELATIVE performance of various aerofoils. Starting with as near a replica of Patient Lady's sail as he could build, Lindsay has tested thirty different sail configurations for Victoria 150's wing, one of which was a biplane rig.

Lindsay's tests showed that his aerofoils were getting a lift coefficient approaching 3.0. He says that the best soft sail rig coefficient is 1.75 while the Finn sail might approach 1.4 at best. However Prof. Bradfield found that Aquarius'fully battened sail which took the Little America Cup from Lindsay in 1976 had a coefficient of 2.0 and Edmond Bruce got the same figure from a pocket luff soft sail. It could therefore be the fact that the Victoria 150 sail was really developing a lift coefficient of 4.2 !!! I think this is unlikely because the maximum coefficient I have ever found for a compound aerofoil of slat, slot and flap was 4.4.

Victoria 150's sail aft of the mast is in two parts separated horizontally at about 40% of the sail height from the top. This is to allow for different aerodynamics at the top. For example, in a strong puff of wind, the lift at the top of the sail could be reduced. Control of all the panels is by carbon fibre rod. It has been stated that there are no less than twelve moving parts to the sail to be controlled.

The "LITTLE AMERICAS CUP" 1985

Defender: Patient Lady Vl. Designer Tony DiMauro and Dave Hubbard. Crew: Duncan MacLane and Skip Banks.

Challenger: Victoria 150. Designer Lindsay Cunningham. Crew Chris Cairns and Scott Anderson.

Course: 19.5 miles around a triangle with 90 degrees and two 45 degree turns. There are eleven legs to sail. The first is a beat to windward up to the right angle. The second is a broad reach with the true wind on the beam. The third leg is a broad reach. As with the America cup, the series is won by the best of seven races.

Place: Roton Point Sailing Association, Connecticut, U.S.A.

Race No. 1

Winner: Victoria 150, by 3 minutes and nearly a mile.

Patient Lady Vl got off to a bad start; made an error of course, was bothered by a tugboat with a barge in tow and a helicopter.

Race No. 2

Winner: Victoria 150, by 30 seconds.

Patient Lady Vl showed marked superiority to windward. Victoria more than made up for this on a broad reach.

Race No. 3

Winner: Victoria 150. Patient Lady's port hull began to delaminate. She retired.

This race allowed a good comparison between the two boats. Patient Lady Vl had the better start due to better acceleration on the wind and led by three boat lengths. She then pulled steadily away to lead by 26 seconds at the weather mark. Rounding this, both boats roared off at twenty knots in the 8 knot wind on the beam reach to the second mark. There was no difference in speed on this leg and Patient Lady rounded again 26 seconds in the lead.

On the third leg at 135 degrees from the true wind blowing at 8 knots, both boats were slower. Victoria sailed straight for the lee mark. Patient Lady Vl sailed a series of S curves, ice boat fashion, bearing up to get speed and then bearing away down the course. I cannot see the value of this myself as the wing could have been let out enough to be unstalled. Certainly, it did not help Patient Lady Vl as she not only lost her 26 second lead but was then 43 seconds behind. However, she began to delaminate on this leg and this was probably contributary.

Race No. 4

Winner: Victoria 150, by 30 seconds. Wind 15 knots Easterly with lumpy sea.

This was a hard fought race with the lead changing several times. The stronger wind must have caused both boats to 'throw away' wind power by reducing the angles of attack of the sails. This would have been advantageous to Patient Lady Vl because her wingsail would have less drag.

ASSESSMENT OF THE BOATS. Observers of the races have said that Victoria 150 was certainly the faster boat. This does not show up in the above account. Instead, we have a picture of two evenly matched boats with Patient Lady Vl improving throughout. It must have been very difficult to get the angles of attack of the sails at their optimum and racing experience against other C Class catamarans of similar performance was probably lacking.

THE CALCULATIONS.

With an all-up boat weight of 500 lbs., we can derive the figures for the boats. Crew weight assumed : 360lbs. Bruce Number 1.8. Br X root L: 9.0. Portsmouth Yardstick: 50. Length to Displacement Ratio 17.6

On the beam reach, we have the guess of a speed of 20 knots in a true wind of 8 knots. This gives a heading to the true wind of 21.8 degrees to which we have to add 5 degrees of leeway to get the beta angle. This gives 26.8.

Still guessing, we can assume a course made good to windward of 45 degrees and a speed of the boat equal to that of the true wind. This gives a beta angle of 22.5 degrees and, removing the leeway angle of 5 degrees, a heading to the apparent wind of 17.5 degrees.

CONCLUSIONS.

1. For these very fast boats, a wing composed of three sections seems faster than one composed of only two sections. The reason for this is that the extra 'slot' delays the stall thus giving extra power downwind by a higher sail coefficient. The upwind penalty does not seem too great. A Handley-Page 'slat' at the leading edge would delay the stall still further and, I once calculated, gave a sail force coefficient of 4.4. Certainly, the slat, slot and flap aerofoil of four parts should be tried at least in a wind tunnel.

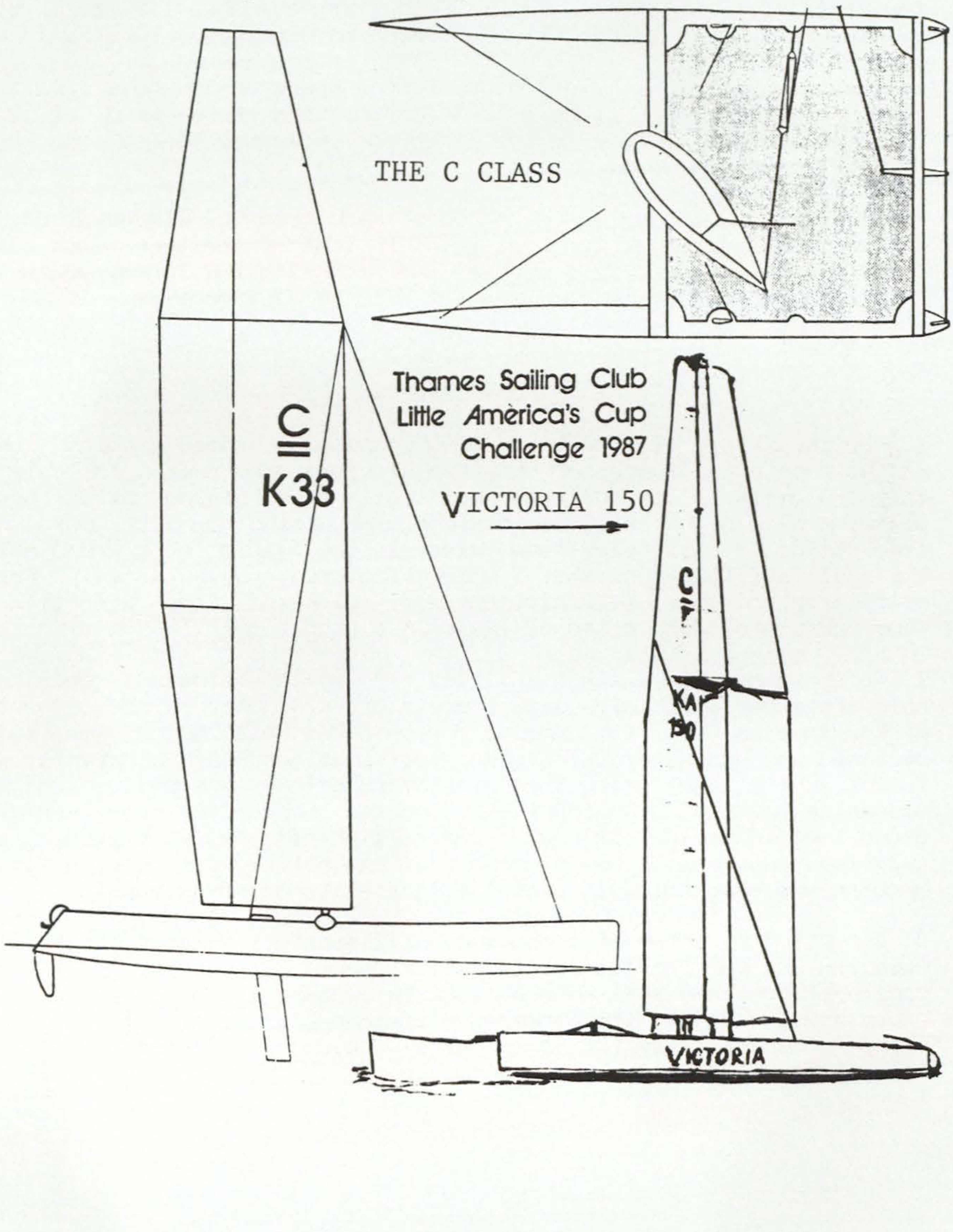
2. As shown by Alex Kosloff in 1976, the 'solid' wingsail does not hold its superiority with slower boats or in lighter winds. In the Little America Cup, his Aquarius V with a Una sail which was fully battened and had a revolving mast, all designed by L.Harvey, was faster in the light going than Miss Nylex with a wingsail. For the slower catamarans, dinghies and keelboats, therefore, the una rig would seem to be the optimum. A semi-elliptical, fully battened and twistless squaresail would probably be better but our A.Y.R.S. members who have tried it cannot tolerate its disadvantages.

3. A section is shown of a compound sail-aerofoil which I think will have the maximum coefficient of sail force. It consists of four panels of battened sail with minimum thickness. It could be set as an 'over the top' wing. Its windward performance is likely to be poor unless the geometry of the parts could be altered. It is, nevertheless, the optimum downwind rig.

THE C CLASS SAIL AREA

The C Class sail area is curiously small. It will be shown later that designers seem to prefer a sail area for dinghies and catamarans of 1.6 multiplied by the length and beam. However, the figures do vary between 1.1 (Tornado catamaran) to 11.26 (18 ft Skiff). The figure for the C Class is 0.86 from 300 sq.ft.. length 25 ft., beam 14 feet.

The small sail area must have made the early, fairly heavy C Class stable sailing. It was also an inducement to adopt the aerofoil sails which are used today with their higher sail force coefficients.



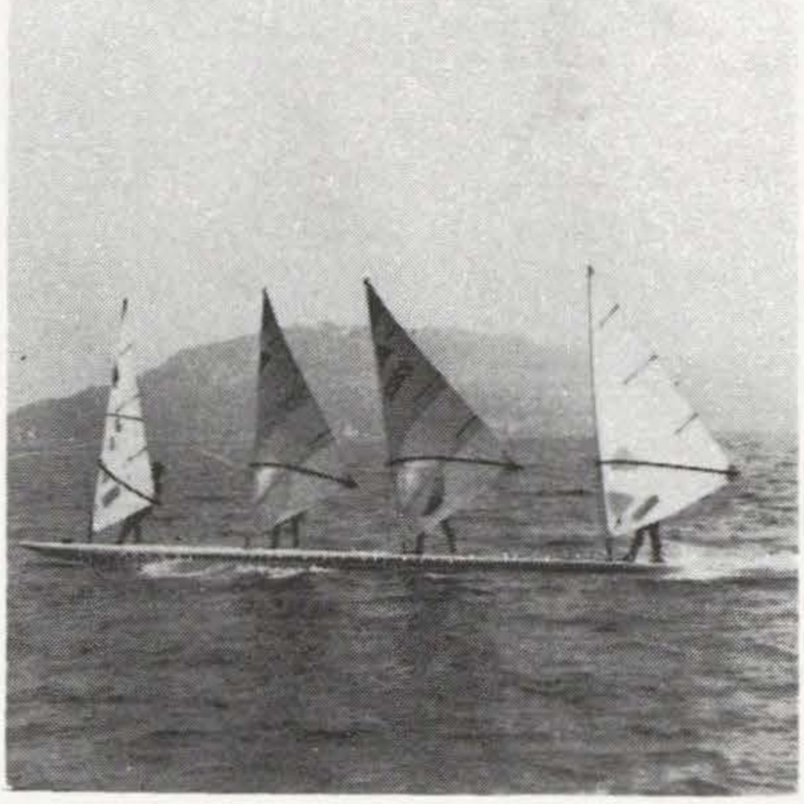
SPEED TO COST OPTIMUM RATIO

The two yachts which stand out far above all others are the sailing surfboard and the Irish lathe and canvas 'curragh'.

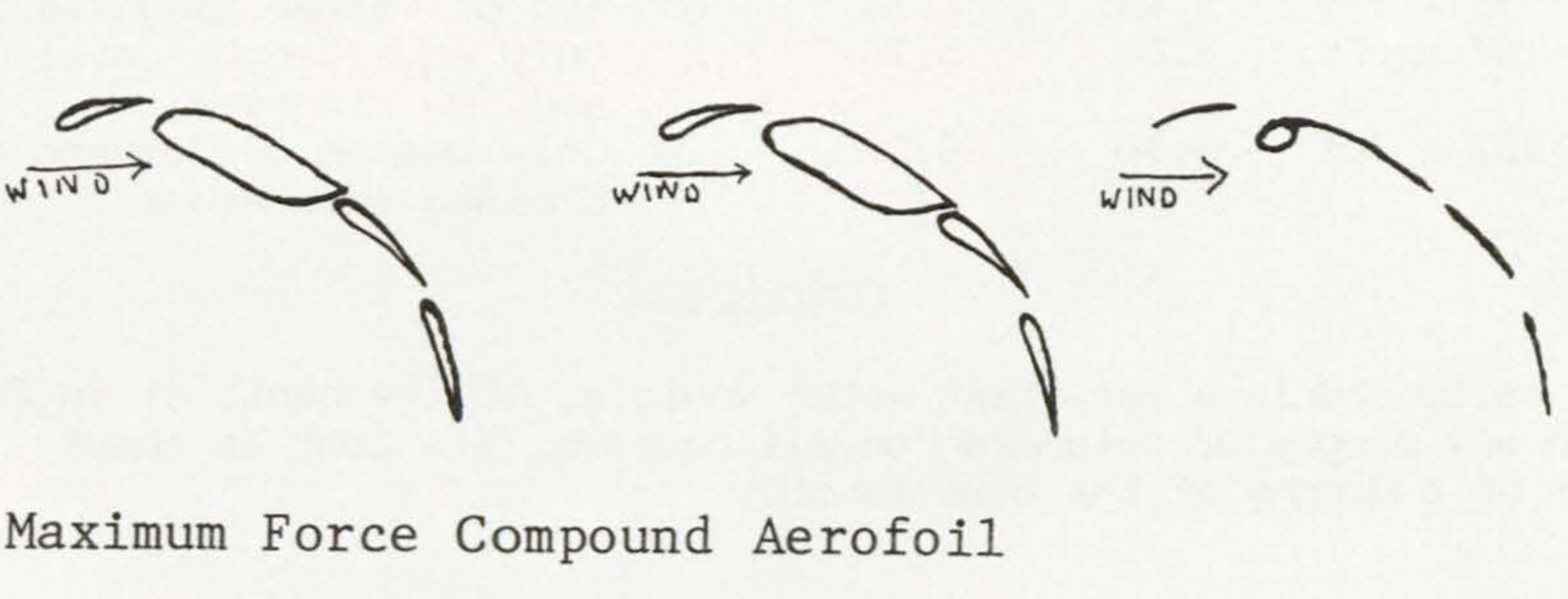
WINDSURFER

L.O.A. 12 ft 0ins	Weight 60 lbs Beam 2 ft 2ins
Displacement 240lbs	Sail Area 56sq.ft to 107sq.ft(10sq.m)

The British courts have accepted that the first sailing surfboard was made by Peter Chilvers in 1958 and that S. Newman Darby made and described another in Popular Science Monthly in 1965 which was reprinted in A.Y.R.S. publication No. 58. However, we owe the modern craft to Hoyle Schwietzer in the U.S.A. who commercially produced and publicised the Windsurfer in 1968.



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



A Maximum Force Compound Aerofoil

The Windsurfer concept is of a flat decked, round bilged surfboard with enough buoyancy to support a person. It has a dagger board and a skeg aft. A mast is mounted on the hull by a universal joint on which a single sail whose clew is held aft by a wishbone boom. The sailor stands on the board and holds the weather arm of the wishbone. He steers by moving the sail fore and aft. There are no stays. We thus have a simple craft which is cheaper than nearly all dinghies. The hull has no windage and the sail is very efficient. The windage of the sailor on the weather side of the sail seems not to be a hindrance and could even increase the sail force.

In countries not covered by the Windsurfer patent, such as Holland and France, variations in board design have been carried out. Length and beam have been changed. Hard chines have been used. The bottom has been given a hollow section. 'V' sections have been used forward. In what is called 'A Sinker', the buoyancy has been reduced so that it has to be moving before the sailor can get on it. The 'Pintail' or canoe stern is reputed in some quarters to give greater speeds.

The top speeds of the Windsurfer are in the region of 18 knots. On 15th April 1985 at Port St Louis, France, Michael Pucher set a record for the 10 sq.m. sail area class of 32.35 knots on a Five Star board. His board measured L.O.A. 8ft 10ins (2.7m) Beam 1ft 5ins (0.43m) Weight 15.4 lbs (7 kg.) Sail area 45 sq.ft (4.20 m2). Six other board sailors exceeded 31 knots at the same meeting where the Mistral wind blew at 45 to 50 knots.

THE FIGURES.

The Windsurfer L.D.R. is 11.26 with a crew weight of 180 lbs. Lighter crews, boards and sails will have larger figures. This figure puts the sailboard into the highly efficient class.

Keen sailboard sailors have several sails of varying areas between 5 and 10 sq.m. which they use in varying strengths of wind. The figures which follow are for the Windsurfer with 56 sq.ft. (Just over 5sq.m.) and 107 sq.ft (10 sq.m.) For both, however, I have taken the figure from our previous research of a 30% improvement for the Una rig and worked that out as well.

Sail Area	Bruce No.	Br.root L	P.N. Estimated.	Comment
56 sq.ft.	1.20	4.17	99	Speed of average dinghy
56 + 30%	1.40	4.76	89	Spd of faster dinghies
107 sq.ft.	1.66	5.76	81	Only equalled by Javelin and 505 dinghies.
107 + 30%	1.90	6.57	70	Only beaten by Tornado & C class catamarans

CONCLUSION

The sailboard is a very fast water vehicle. At its best, it is faster than any dinghy or catamaran on all courses. Its cost is about half that of a dinghy of the same length.

THE IRISH CURRAGH

A Curragh from Kerry (Photo from Irish Tourist Board)

The curraghs of the West of Ireland, especially Co. Kerry, all look the same but differ from builder to builder. Typical proportions are as follows :

L.O.A. 27 feet. L.W.L. 22 ft., "L" 25 feet.. Beam 4 ft., Weight 230 lbs. Displacement (2 crew) 590 lbs.Sail (rarely used) about 75 square feet.

The curragh is a lathe and canvas boat of very ancient lineage. As a split hazel or willow boat covered with tanned skins, it was seen by Julius Caesar in England. It may well have been invented in the bronze age.

St. Brendan, (c.484-578) with 14 other monks cruised up the coast of Ireland and called on St. Columba in Iona in one (or three) curraghs. He then went on to discover North America. The 'Navigatio' which describes the voyages is short of details which can precisely identify where he went but Medieval maps show "Brendan's Islands" placed anywhere from the Azores to the Canaries i.e., well out in the Atlantic. I went through professor O'Meara's translation to see if a) there was any lateral resistance and b) one large or three small curraghs were used. I found that: a) Windward sailing was accomplished by trimming the sail- -and rowing. Lateral resistance was therefore unlikely. b) 'Take your boat out of the water high up on the land' seems to indicate that the boat was fairly easily carried as is the 24 foot curragh. A large curragh such as Tim Severin's "Brendan" to hold 15 people could not have been carried by them. Although the word for boat (navis or navicula) is always singular in the text, common sense suggests the use of three small boats, instead of one.

The curragh is remarkably seaworthy and is reputed to have survived sudden Atlantic storms which have sunk plank- built boats. This will be examined later.

CURRAGH FIGURES

The boat weight is 130 lbs. Three men can turn her over and carry her over their heads. This gives an L.D.R. of 21.6, with 360 lbs of crew. It takes an all-up weight of 2273 lbs. To reduce the L.D.R. to the optimum figure of 11.0 so we can be sure that the curragh is a good weight carrier. I have worked out the figures with 75, 100 and 150 sq.feet of sail and assume the use of a centreboard.

The figures in brackets are for a displacement of 2273 lbs.

Sail Area	Bruce No.	Br. X root L	Estimated P.N.
75 sq.ft.	1.03 (0.66)	5.16 (3.29)	90 (120)
100 sq.ft.	1.19 (0.76)	5.96 (3.8)	83 (110)
150 sq.ft.	1.46 (0.93)	7.30 (6.66)	73 (95)

CONCLUSIONS

1. The speed of the unballasted curragh with 75 sq.ft of sail is that of the average dinghy such as: The 420, Laser, Laze E, Lightning, Pegasus, Scorpion, Swordfish, Wineglass and Wildfire.

2. The speed of the unballasted curragh with 100 sq.ft. is comparable with that of the very fastest dinghies such as the 505, Javelin, Tempest. Only the International Canoe, 18 foot skiff and Flying Dutchman are faster.

3. The speed of the unballasted curragh with 150 sq.ft. is greater than all dinghies and multihulls other than the Tornado and C Class catamarans.

4. The unballasted curragh with 100 sq.ft. of sail sails at the same speed as the Windsurfer sailboard. It has a P.N. of 83, while the sailboard using 10 sq.m. has a P.N. of 81.

5. The curragh ballasted to a displacement of 1540 lbs will sail at the same speed as the faster dinghies. COST It is said that the cost of a curragh is about one tenth of a similar sized plank-built boat. In the 1960's, the price was £ 75.

SPEED TO HOME-BASING RATIO

The cheapest, easiest and method of least worry to keep a boat is at home. Obviously, it is best to keep it in a shed or garage but many people keep boats in the open on trailers in their gardens. Then, when one wants to sail, the boat is towed by car to the water and launched.

More satisfactory than using a trailer is to have a boat which can be carried on the roof of the car - the so-called "car-toppers". The commercial success of many boats depends on this facility such as the Laser (14 feet O.A.), the Moth (11 ft O.A.) and the sailboards (12 feet O.A.or less), especially these last. Every day, one sees sailboards jauntily on the tops of cars anywhere near the coast or sailing waters. This occurs to such an extent that I sometimes wonder if they are always there as a kind of 'status symbol' to give a macho image to the owner. However, one also sees boats being towed on trailers.

The British and U.S.A. regulations for the dimensions of trailers and their loads which can be towed by car on the roads decree a maximum length and maximum beam. Because length means speed, we must aim for the maximum which is about 26 feet and a beam which can be reduced to about 7ft 6" However, there is more than enough effort to rig a boat when it is launched without having the hulls and outriggers to work on. We would prefer our boat to have a sailing beam of 7ft 6ins. The commercial success of the Shearwater 111 catamaran which has this beam with a length of 16 ft 6ins is founded on this preference.

CLASSIFICATION.

In order to make this section manageable, we need a classification. This is :-

1. Car-toppers
2. Boats within the trailer restrictions
3. Trimarans and Melagasy outriggers with "Swing-Wings".
4. Catamarans and trimarans with beam reducible by folding.
5. Multihulls which have to be assembled at the water.

CAR TOPPERS The sailboards are the obvious optimum here. As above, the Laser, Moth and even Fireball (L.O.A. 16 ft 2ins, P.N. 85) have been car-topped, though they are also towed on trailers.

TRAILER BOATS. The optimum here is the curragh with 150 sq.ft. of sail which could be two Laser sails of 75 sq.ft.each, and a crew of two. P.N. 73. The Shearwater is next (L.O.A. 16 ft 6ins beam 7 ft 6ins. P.N. 75) The ten best dinghies from the figures are 10 sq.m. International canoe,, 505, Javelin, Fireball, 470, Contender, 14 ft International, Finn, Lark, Laser.

"SWING-WINGS". John Westell (Treetops, Barracks Hill, Totnes, Devon,U.K.) is the main protagonist of these - but only for larger boats. The cross arms 'pantograph' on eight pivots. This allows the floats or foils to be brought alongside the hull for trailing. The cross arms are held out when sailing by a single wire strung diagonally on each side. I do not know of any racing application but a 25 ft.'swing-wing' Melagay outrigger could be built to be very light and hence have a performance similar to the C Class catamarans.

BEAM REDUCIBLE BY FOLDING. Various A.Y.R.S. members have suggested folding cross arms for trimarans whereby the floats are folded downwards to the main hull. Catamarans have been built with hinges in the cross beams to fold the hulls together. all these have been 'trailer-sailer' craft with no real attempt at speed.

BOATS FOR ASSEMBLY. This comprises the C Class catamarans and Tornado as the fastest examples. Both have been made fairly easy to assemble but it is an extra chore to add to the rigging of the boats.

THE "SAILER-TRAILER" MONOHULL. In the last decade or so, there have come on the market several monohulls with retractable ballasted keels and often some inside ballast to make them stable. They have a couple of berths, galley and heads. They are usually about 18 to 20 feet long and 6 to 7 feet in beam. They are towed to the water, launched, sailed and possibly slept in. Finally, they are retrieved and taken home. They give a great deal of pleasure but have no great speed.

THE SWIFT 18 TRAILER-SAILER FROM HONOUR MARINE

SPEED TO SAIL AREA RATIO

In general, we start by thinking that the more sail area a yacht has, the faster will be her speed. However, if a yacht has too much sail area, it cannot use it all on many sailing days and this restrains the amount of sail so that, as we shall see, there is an optimum amount of sail for every boat.

Because speed is proportional to the Bruce Number multiplied by the square root of the length, for any given amount of sail area the speed will be greater if the length of the boat is increased and the displacement reduced. This favours the long light curragh and the sailboard.

Speeds for a given sail area can also be increased by increasing the efficiency of the sail. There has been little research into aerofoil sails except in the C Class catamarans. The symmetrical aerofoil is a poor performer as compared with sails but a single asymmetrical aerofoil has been shown to be very good. With a Handley Page slat, perhaps a slot and flap, the performance could be better still. For sails as we know them, the Una rig with a single fully battened sail and a rotating mast is clearly the best we can do. In the low windspeeds at which yachts mostly sail, it may even be better than complicated and expensive aerofoils.

THE RESEARCH Seventy-one yachts were used from Rhonda Budd's book. Because, as we have shown, the speeds, as given by the Portsmouth Yardstick numbers, seem to be derived in light winds, an attempt was made to find the speed in relation to the wetted surface areas of the yachts.

The yachts used were mostly dinghies with a few ballasted monohulls. These are generally all of the same shape so it was thought worth while simply to take the product of the length multiplied by the beam as an index of the wetted surface. This gives a somewhat distorted picture because of the different amounts of flare in the topsides. However, figures have been produced which seem more or less in accordance with the other researches given in this publication.

The formula for the sail area to wetted surface ratio was taken to be:

$$\frac{\text{Sail Area}}{\text{Length X Beam}}$$

The figures for this were worked out for the 71 yachts. They varied from 1.05 for the Moth to 2.00 for the Turtle, an 11 ft 5 ins. dinghy and 2.04 for the Albacore (15 ft.). The 'over-hatted' Flying Dutchman's figure was 3.59 and that for the Australian 18 ft. Skiff was no less than 15.02.

THE RESULTS.

It had been hoped that speeds, as given by the inverse of the Portsmouth Number could be graphed against the figures for 'wetted surface' and that they could possibly be better than the Br. X root L graph. Unfortnately, this was not so. There is far too much scatter. Many boats with large sail areas are slow while many with small sail areas are fast. The best picture is obtained by making groups of boats as follows

$\frac{\text{S.A.}}{\text{L X B}}$	1.05	1.20-1.30	1.30-1.40	1.40-1.50	1.50-1.60	1.60-1.70
No.Boats	1	4	5	10	10	18
Av P.N.	107	12	98.8	97.5	100	92.0
Range		95-144	91-105	83-103	81-122	85-112

$\frac{\text{S.A.}}{\text{L X B}}$	1.70-1.80	1.80-1.90	1.90-2.00	2.00-2.10	3.59	15.02
No. Boats	14	3	2	2	1	1
Av. P.N.	96.2	86.7	91	10	78	73
Range of P.N.	81:116	78-100	88-94	94-118		

OBSERVATIONS

1. In general, the speed of yachts is increased by increasing the sail area to the product of length and beam.

2. Designers appear to prefer a ratio of 1.6 to 1.7 (one quarter of the boats)

3. There may be an optimum ratio in the 1.6 to 1.7 range.

THE EXPERIMENTAL RACING CLASSES

To my knowledge, there are only three classes of sailing yachts which are totally unrestricted in one vital respect. These are:

1. The Bembridge Redwings, sailing from Bembridge, Isle of Wight. These are free to set 200 sq.ft. (18.58 sq.m) on a one design keel hull in any way they like. Many rigs have been tried from the Chinese Junk to the Ljungstrom rig. Lord Brabazon tried an 'autogyro' rotor. The most successful rigs have been sloops with a very high aspect ratio mainsail.

2. The C Class catamarans. These have already been described. Their optima have been a) A fully battened Una rig with rotating mast (Aquarius V) which seems to be better in light winds. b) The compound aerofoils which have been winning recently.

3. The Skerry Cruisers which can have any hull they like using 22 sq.m, 30 sq.m, 75 sq.m and 150 sq.m. In origin, they come from Scandinavia. Their figures, as given by Uffa Fox in his books are as follows:

22 sq.m. Vigilant. L.O.A. 34 ft 6ins. L.W.L. 25 ft 6 ins. "L" 30 ft. Beam 6 ft 4ins. Displacement 2 tons. Draft 4 ft 3. Sail Area 236 sq. ft. Br. 0.93 Br root "L" 5.1 L.D.R. 10.3, Sail area/ "L" X beam 1.24 Estimated P.N. 84

30 sq.m. Waterwitch. L.O.A. 43 ft 6ins. L.W.L. 28 ft 6ins "L" 36 ft. Beam 7 ft 2ins Displ. 2.74 tons Draft 4 ft 11ins. Sail area 323 sq.ft. Br 0.98. Br X root "L" 5.88 S.A./ "L" X B = 1.25

75 Sq.m. Bacchant L.O.A. 63 ft.11ins. L.W.L. 43 ft.6ins. "L" 53,71 feet. Beam 9ft 7ins. Displ. 10 tons Draught 7ft 5ins Sail area 807 sq.ft. Br 1.00 Br.X root "L" 7.38 L.D.R.: 11.3 S.A./"L" X B: 1.57

With these three similar boats but of increasing size one notes:

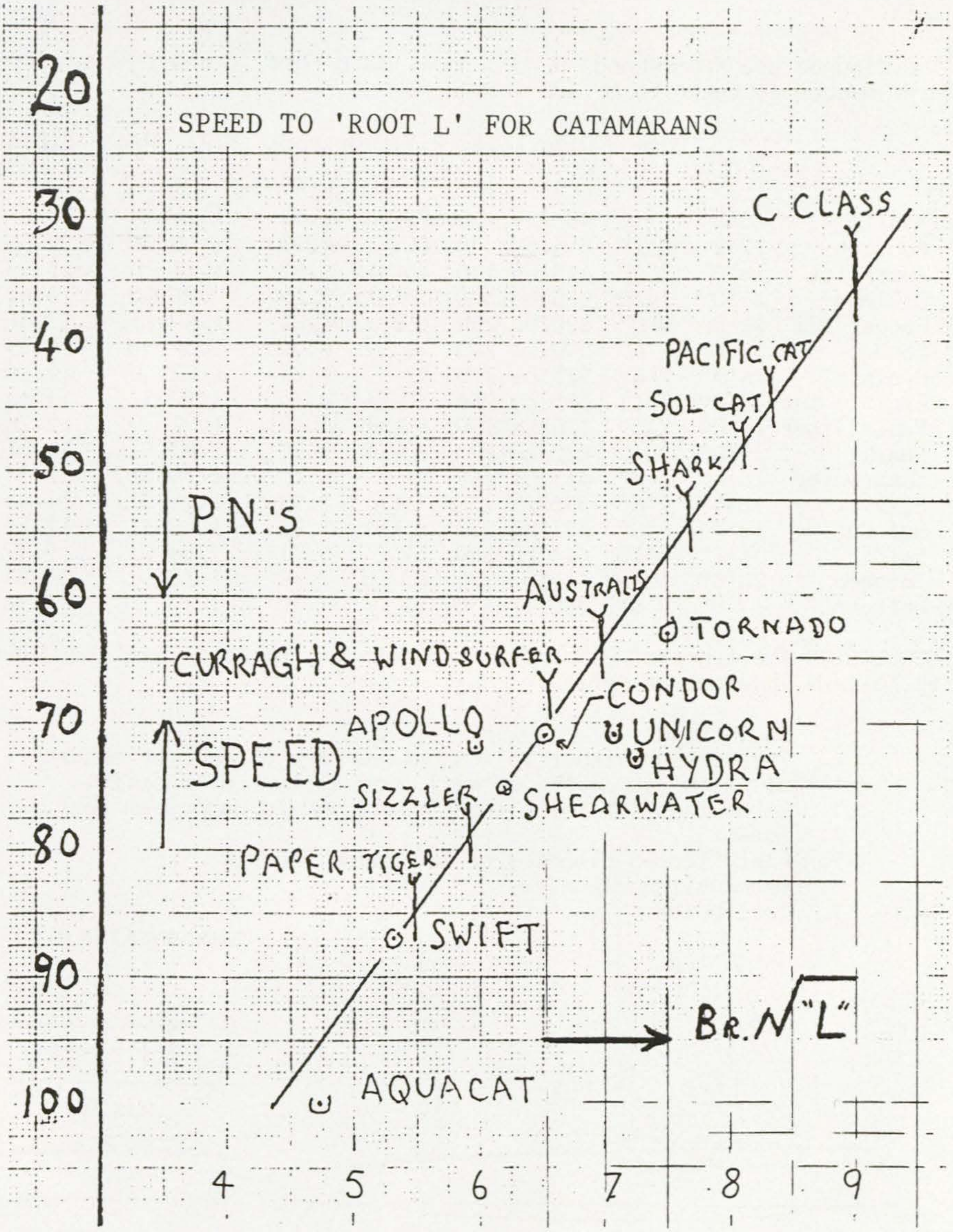
1. The Bruce number increases -	0.93,	0.98,	1.00
2. The Br. X root "L" increases -	5.1,	5.88,	7.38
3. The L.D.R. STABILISES at the 11 mark -	10.3,	11.6,	11.3
4. The S.A./"L" X B increases -	1.24,	1.25,	1.57

These show that speed increases with size. The rather massive increase in sail area of the 75 sq.m. is due to a disproportionate increase of stability with size.

THE SPEED TO SAIL AREA RATIOS OF CATAMARANS

So far, we have shown that catamarans obey the speed to Br. X root "L" rule. The reason for this is not clear because catamarans have less wetted surface, more stability and less wave making than dinghies. For instance the Shearwater has less wetted surface than a Firefly dinghy.

Catamarans also have relatively less sail area than dinghies. This is due to their greater speed to windward with its associated extra apparent windspeed. Rhonda Budd lists 16 catamarans of which no less than 7 have a Sail area/"L" x B of less than 1.13 while that of the C Class os 0.86. It is, however, just possible that the C Class is under-canvassed which has led to the aerofoil sail development.



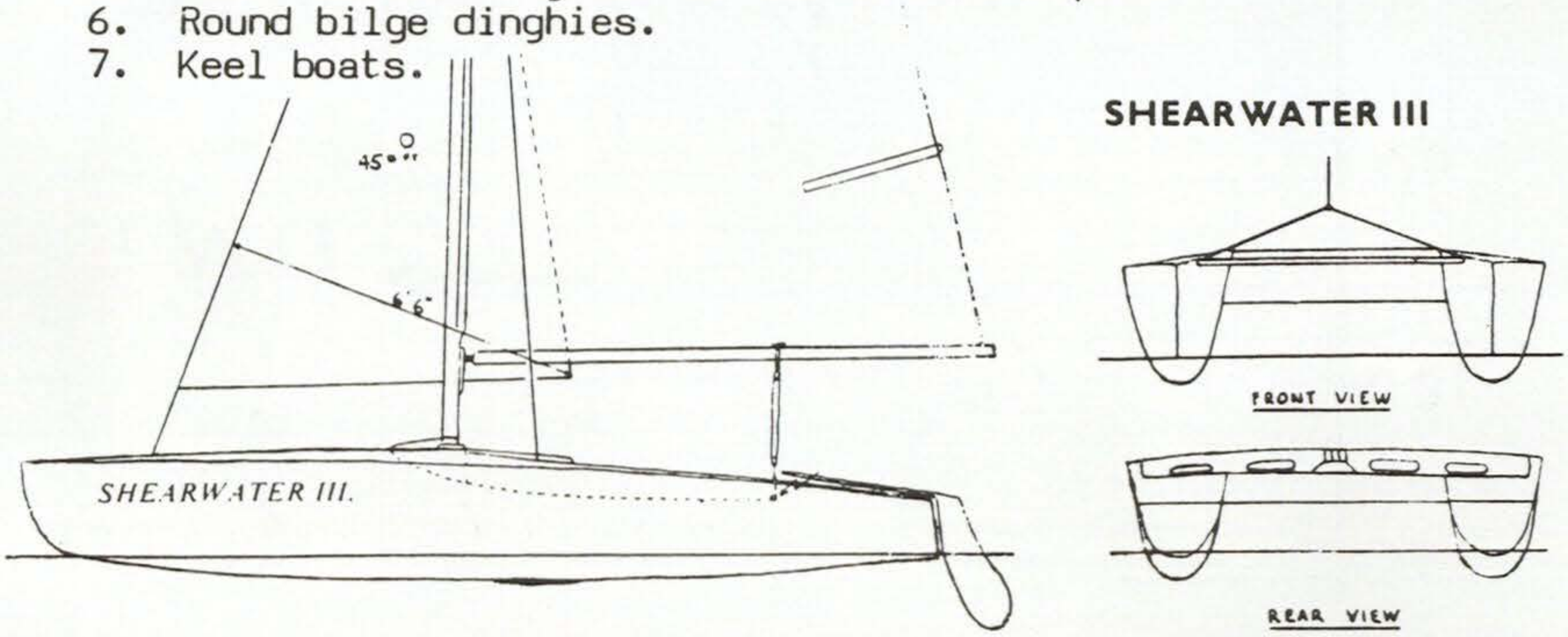
The figures and graph may be of interest. The graph is probably the straight line I have drawn although there are not enough Portsmouth Numbers to be sure. The vertical lines give that Br. root "L" where the Portsmouth Number is not known. From them, one can estimate the likely Portsmouth Number. The Tornado, Unicorn and Hydra are below my line and the Apollo is a bit above it. I cannot see any reason for this.

The figures are from Rhonda Budd's book. As before, the weight of one crew member is taken to be 180 lbs.

	"L"	Beam	Disp.	S.A.	P.Y.	Br.root "L"	S.A./ "L"X B	Rig	L.D.R
Apollo	18'0	7'6"	480lbs	150	72	6.64	1.11	U	14.6
Aquacat	12'2	6'1"	345lbs	78	100	4.39	1.05	U	9.59
Australis	18'0"	7'6"	415lbs	150	75Est.	6.97	1.11	U	15.73
C Class	25'0"	14'0"	810lbs	300	55Est.	9.29	0.86	U	18.42
Cougar 111	18'9"	8'0"	620lbs	250	60Est.	8.02	1.67	Sl.	13.68
Condor	16'0"	7'4"	570lbs	183	71	6.52	1.56	U	11.25
Hydra	16'3"	7'6"	525lbs	210	73	7.24	1.72	U	12.00
Pacific Cat	18'6"	7'11	595lbs	266	60Est.	8.34	1.82	Sl.	13.69
Paper Tiger	14'0"	7'0"	320lbs	100	85Est.	5.47	1.02	U	12.28
Shark	19'0"	10'0"	810lbs	273	63Est.	7.73	1.43	Sl.	12.21
Shearwater	16'6"	7'6"	615lbs	168	75	6.19	1.36	Sl.	11.33
Sizzler	16'5"	7'6"	595lbs	150	79Est.	5.92	1.22	Sl.	11.44
Sol Cat	18'3"	8'0"	675lbs	220	65Est.	7.22	1.50	Sl.	12.58
Swift	14'6"	5'10"	611lbs	140	87	5.31	1.66	Sl.	9.37
Tornado	20'0"	10'0"	640lbs	220	63	7.70	1.10	Sl.	14.83
Unicorn	17'8"	7'6"	380lbs	150	71	7.30	1.13	U	15.98

CONCLUSION The types of yacht with the greatest speed to sail area are as follows in order of merit :-

1. Sailboards
2. The curragh either in its native form or made of modern materials with 150 sq.ft. of sail such as two Laser sails.
3. Catamarans, of which the C Class and Tornado seem best.
4. Scows.
5. Flat floored dinghies or New Haven Sharpie.
6. Round bilge dinghies.
7. Keel boats.



SPEED TO LENGTH OF OPTIMUM YACHTS

In considering this item, we find different horses for different courses. If the length is twelve feet or thereabouts, the sailboard will certainly be the fastest. However, sailboards of say, 24 feet in length with a crew of two, each with his own sail, have not proved to be faster in the Weymouth Speed Trials. I do not know if they are faster in light winds than the ordinary sailboard.

The reason for the inferiority of the 24 foot sailboard is hard to see. The board itself should have less than twice the resistance of a 12 foot board while one would think that the sail drive would be doubled. We can only presume that there is some interference between the two sails which prevents them from achieving this doubling. If the 24 footer is faster than the 12 foot board in light winds, however, we will think that the top speeds of the sailboard is got by the act of tilting the sail to windward to let the wind lift up the sailboard, thus reducing its displacement.

I have never heard of an encounter between a 25 foot sailboard and a C Class ctamaran. I wonder if the Little Americas Cup rules would allow it ? The only figures of speed for the two which I have are their "Speed ratios" or VB/VT (boat's speed over true wind speed). The sailboard has a

ratio of 1.4 while the C class can do 2.5 on a slightly free course. However, these figures are not comparable because the figure for the sailboard was taken when travelling at near its top speed.

DESIGNING FOR TOP SPEED TO LENGTH.

Because speed depends on length, sail area and displacement, if length is fixed, one will get the highest speed by increasing the sail area (or sail power)and reducing the displacement and wetted surface.

THE HULL

As shown by Tim Coleman's MacAlpine-Downie designed Crossbows 1 and 11, which pushed up the sailing speed record to 36 knots, the optimum is long very lean single catamaran hull of 50 to 60 feet in length. Tim held his Crossbow 1 upright by a windward outrigger with a planing shoe all of which came clear of the water during the speed runs. To increase stability, a crew of four ran out to windward as the float lifted. Watching this performance, it was obvious that, as the float lifted and speed increased the heeling moment of the sails also increased as we would expect from the increase in apparent wind speed. This often needed the sheets to be eased to prevent a capsize.

One hesitates to suggest any improvement on such a marvellous craft but at these speeds and for a 'starboard tack only' boat, asymmetry of both the main hull and float,as shown by the Hobie cat and, of course, the Micronesians, should be of value. The float could be of Melagasy type but it would slope up towards the main hull. Asymmetry of both main hull and float would remove the need for the centreboard and the foil on the float.

THE SAILS

On Crossbow 1 Tim Coleman used a conventional sloop rig. The sail coefficient of this is 1.2, as far as I can gather. A fully battened single sail with revolving mast would give a coefficient measured at from 1.7 to 2.0. The C Class Victoria V rig give a coefficient of 'nearly 3.0'. I feel sure that a fully battened multiple sail system with four units giving a 'slat', slot and flap would give a coefficient in excess of 4.0. It is an open question, however, if the 'lift to drag' ratio of such a sail would be useful. If it is too big to be used, reducing the panels to three might be the answer.

A SUGGESTION

Few people either could or would want to build a 50 foot 'one way' proa like Crossbow 1. Nor is it necessary. A 25 foot boat of any kind will accurately do 70% of the speeds of a 50 foot one of the same model. It is enough to have an 'open' class limited to 25 feet. Such a class introduced into the Weymouth Speed Trials would allow the development of the Crossbow concept or any other type of speed machine. Then, if such a boat went at 28 knots, or more, one would be reasonably certain that a 50 foot version could break into the 40 knot speed range.

THE C CLASS CATAMARANS.

These must be the fastest racing boats for their length with a V_B/V_T of 2.5.

I am not sure, however, that a 25 foot sailboard with two crew and a sail area of 20 sq.m.(214 sq.ft.) in the two sails would be less fast in light winds. A 25 foot proa with a windward float of sailboard proportions and canted up to leeward must surely have less weight and wetted surface. Moreover, it could usefully set a semi- elliptical , fully battened 'squaresail', as shown by a certain Captain Mellonie in an early A.Y.R.S. publication. The Micronesians were sailing such craft around at 20 knots when first visited by Anson.

HYDROFOIL BOATS

Although hard for the rest of us, it appears easy for geniuses such as Philip Hansford and James Grogono to 'fly' on hydrofoils. So far, the speeds have been good but not outstanding. The high aspect ratio foils seem to produce a lot of resistance. The answer could lie in very low aspect ratio, like tiny sailboards. Philip Hansford is now experimenting with inverted T foils.

DINGHIES.

It is obvious from our studies that dinghies can never be as fast as catamarans no matter how much sail area is piled upon them. Uffa Fox produced a curragh like dinghy for the second Cross Channel race from Folkestone to Boulogne in 1958. It was 25 feet long by 4 feet in beam. Unfortunately, the mast broke as it set out and we never discovered its potential.

BALLASTED KEEL YACHTS

The fastest of these are :-

1. The International 110. This, again, is a boat of curragh like proportions. It is a canoe sterned craft with vertical stem and sternposts. The length is 24 feet and the beam, with very little flare, is 4 ft.2ins. The sail area is 167 sq.ft. The hull weighs 900 lbs. of which 300 lbs are in the keel. I estimate the Portsmouth Yardstick number as 80.

2. The Tempest is more of the dinghy in shape and proportions. The length overall is 22 ft.0ins. The L.W.L.is 19 ft.3ins. The beam is 6 ft.4ins. The sail area is 247 sq.ft. The boat weight is 1,100 lbs. of which 500 lbs. are in the retractable fin keel. The Portsmouth Yardstick number is 82.

Obviously, neither of these is a contender for speed in anything but against their own kind.

CONCLUSION

The optimum speed to length ratio is to be got by a 'Pacific proa' (float to windward) with the following attributes :-

1. Asymmetric main hull.
2. A float of sailboard proportions, canted up to leeward.
3. A semi-elliptical, fully battened 'squaresail'.

SPEED TO DISPLACEMENT RATIO OPTIMUM YACHT

Although even the smallest dinghy is a vehicle for carrying weight, that is, the weight of people, we will confine ourselves in this section to larger craft carrying commercial cargos. The last of these were ekeing out a living about 50 years ago. Because they are no longer economic, one may now call them yachts.

There are, at present, some efforts to design and build commercial sailing ships. Some ingenious and handsome designs have been produced. The Japanese have used computer controlled sails on some of their cargo ships to economise on oil. However, the cost effectivenes of this work must surely be in doubt.

It may be thought impertinent of me to apply the figures for sailing yachts to commercial vessels when test tanks all over the world have been studying the shape of ships for least resistance for 100 years. Moreover, they are so very much larger in many cases. On the other hand, there is evidence that the figures apply. For instance, the Atlantic Liners which used to cross from Southampton to New York in four days have a length to beam ratio of 11:1 and a box section with rounded off corners which is not far away from a semi-circle. This may be compared with my L.D.R. (Length to displacement ratio) which appears to be optimum for small yachts when it also is 11.0.

THE METHOD OF STUDY

The performance related figures will be worked out for three commercial sailing vessels and the estimated Portsmouth Yardstick figures derived. This will be done both when empty and with their guessed weight of cargo. I have the dimensions of three such craft but all have some vital ones missing. These gaps will be filled as best I can. The three are :-

1. The Thames barge. This craft, though often plying along the East Coast of England, was mainly concerned with supplying farm produce to London from the farms of Kent and Essex. A lot of it was to do with supplying the enormous number of horses in London with hay and oats and bringing back horse manure to the farms.

The main need was for a barge to be able to beat well to windward against the westerly winds. To get to the farms, the draught had to be low and when the railways came into competition, the crew was finally reduced to two men, generally called 'man' and 'boy'.

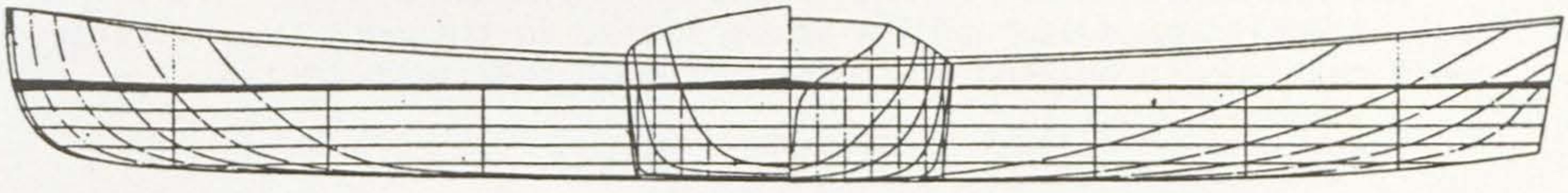
Up to about 1830, the Thames barge was a flat floored scow called the 'swim-head' type. It had hard chines carried right to the bow and stern and was thus cheap to build. For windward work, leeboards were used. In the latter half of the 19th Century, England became more prosperous and the Thames barge developed yacht-like lines though full at the ends. The hard chines shrunk to only one fifth of the length to give support to the leeboards. One barge was built with rounded sections throughout, thus abolishing the chines altogether. This was very slow to windward, making a lot of leeway due, one supposes, to the lack of enough lateral resistance. If the larger, asymmetrical leeboards of the Dutch "Botter" had been used, it might have been a success. However, using the saying "It was tried once and did not work" which was applied to multihulls in the 1950's, no more round bilge barges were ever built.

THE RIG. The rig for small boats in north-west Europe since Medieval times has been the sprit. It appeared in Holland along with the leeboard and the central stern rudder. At the same time, a balanced lug of sorts appeared in Venice. All these four items were known in China previously and I believe Marco Polo (1254-1324) and his companions described the Chinese features to Europeans who adopted them.

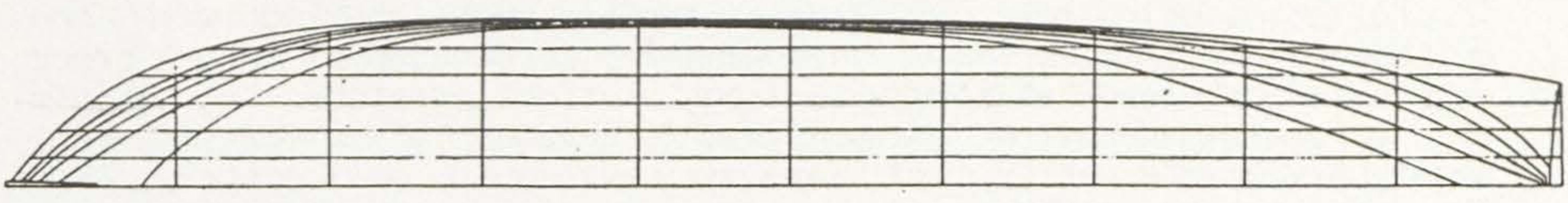
The origin of the Thames Barge is unknown to me but, as larger boats from about 30 feet to 35 feet in length upwards used a single squaresail, one must believe that it began its existence as a small scow with spritsail and leeboard and gradually grew large.

The important item in the use of the Thames Barge's loose-footed spritsail is its ability to be both 'reefed' and furled HORIZONTALLY to the mast by brails or ropes running from the mast through grommets at the leech of the sail and back to the mast. This allows one man to take in the mainsail by turning a winch handle. The topsail, jib and mizzen are small sails, easily dropped. The leeboards can be used as brakes in shallow water. All these features make the barge easy to handle.

The efficiency of the spritsail is not particularly good with a coefficient of 0.8, as compared to 1.0 for the gaff rig and 2.0 for the fully battened Una rig. However, it was adequate enough in the small sizes and probably increased in the Thames barge, because of the topsail, to become 0.94.



LINES AND SECTIONS FROM "GIRALDA" UFFA FOX'S SECOND BOOK.



THE NORFOLK WHERRY.

On first seeing the Norfolk wherry, it is immediately recognizeable as a Viking 'Longship' of which there is an example at Pegwell Bay, near Margate, Kent. The fine lines, the canoe stern and the clinker (lap-strake) planking are common to both. It is not surprising therefore to learn that, up to about 1800, it used a small squaresail of more or less Viking proportions but was called a 'keel' a term probably arising from the fact that it had a long keel below the boat to enable it to go to windward.

The term 'wherry' is basically applied to small rowing, passenger-carrying boats which plied for hire or ferry purposes on the Thames and other rivers. The origin of the word 'wherry' is, apparently obscure but I like to think that it comes from the obvious question "Where are ye going", shortened to "Where ye ?" which became Wherry.

The Norfolk alluvial plain is crossed by rivers running from the higher ground in the West to the East coast. In Medieval times and probably long before that people had been digging peat for burning in various places near the rivers. They thus lowered the ground level and, when the sea level later rose by some four feet, the old peat working became flooded to form lakes known as the 'Norfolk Broads'. Up to the 20th century, there were few roads and the farms in the area were very isolated. The people therefore had to take to the water to get their produce to the market towns which grew up on the rivers. Their transport were the keels and later the wherries.
The squaresail of the keel was powerful, close-winded and efficient. However, when beating to windward up the Norfolk rivers, they are likely to have lost their weigh when putting about and this needed a

lot of shoving and pushing with their 22 foot 'quants' to get them sailing again. This in turn needed a crew of several men. In contrast, the wherry with a single gaff, loose-footed sail, put about simply by putting the helm down or, if large, the bow could be given a shove to turn the craft without losing weigh. Thus, the keel was replaced by the whery and the last keel was built about 1795. The wherries then did all the carrying trade through the 19th Century and in the 20th Century until the advent of the motor lorry. In the end, some wherries could carry up to 40 tons of cargo, although most were smaller.

THE WHERRY SAIL

The gaff sail with its loose foot is remarkably close- winded, the wherries could creep up narrow dykes, only getting an occasional 'cupful of wind', simply using their momentum or by shoving with the quant when all else failed. I have wondered if occasional large trees were allowed to grow at intervals along straight stretches to deviate wind across them. Some of the man-made stretches of river zig-zag, apparently unnecessarily, and these may have been deliberately made for sailing to windward.

Combined with the efficient sail, an extra 'slipping keel' could be bolted on below the main one to give some extra grip on the water. This keel could be taken off when going up the shallower dykes, rivers and canals.

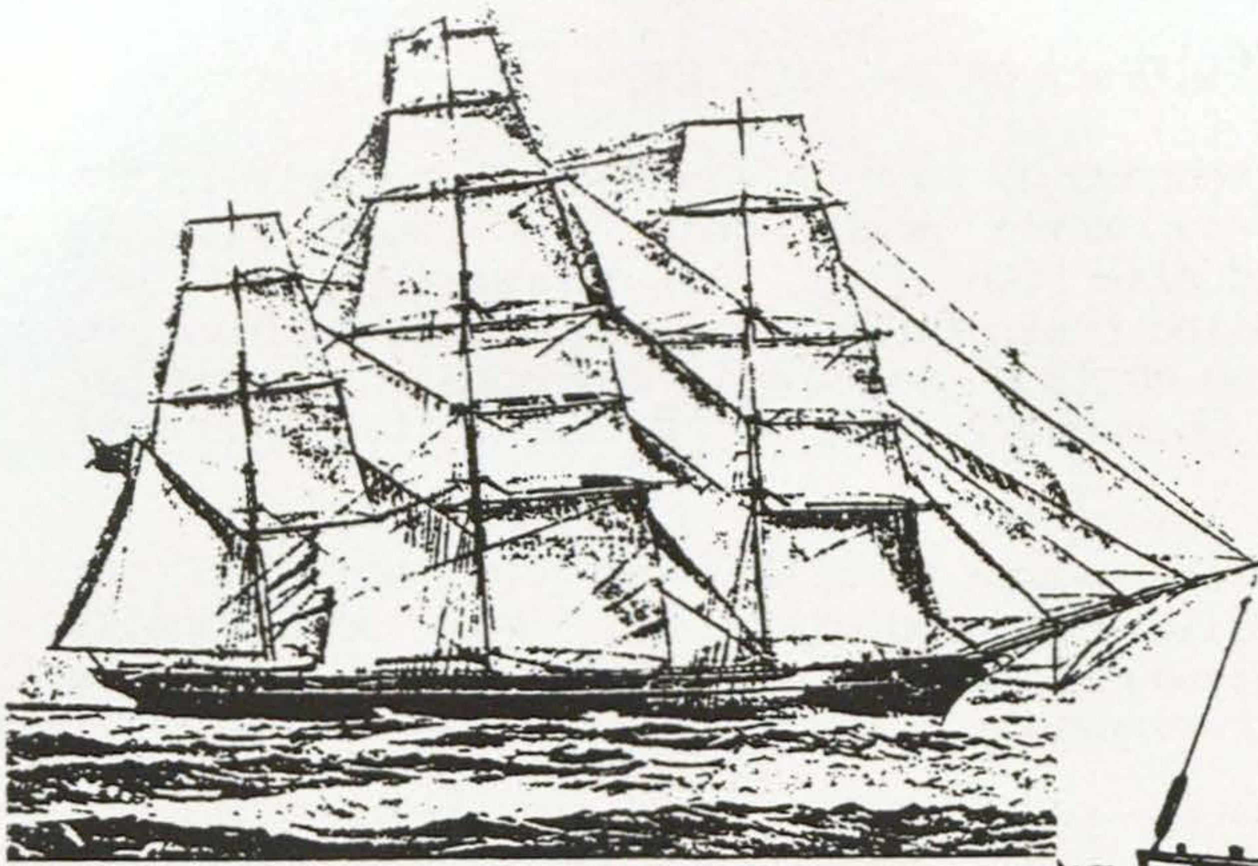
THE SQUARE RIGGED SAILING SHIP

Whenever and wherever boats with some stability and skins existed together, the square rig would have been invented. One can therefore place it firmly in the Neolithic (new stone age) period, if not before. In prehistoric Egypt, quite large ships have been found as rock carvings dating from 4,500 B.C. A single squaresail of aspect ratio 1.5:1 was used. The hull then and throughout the "Old Kingdom" of Egypt (2770-2270 B.C.) for commercial ships was a narrow and deep scow to give lateral resistance. They would have been able to beat quite well to windward.

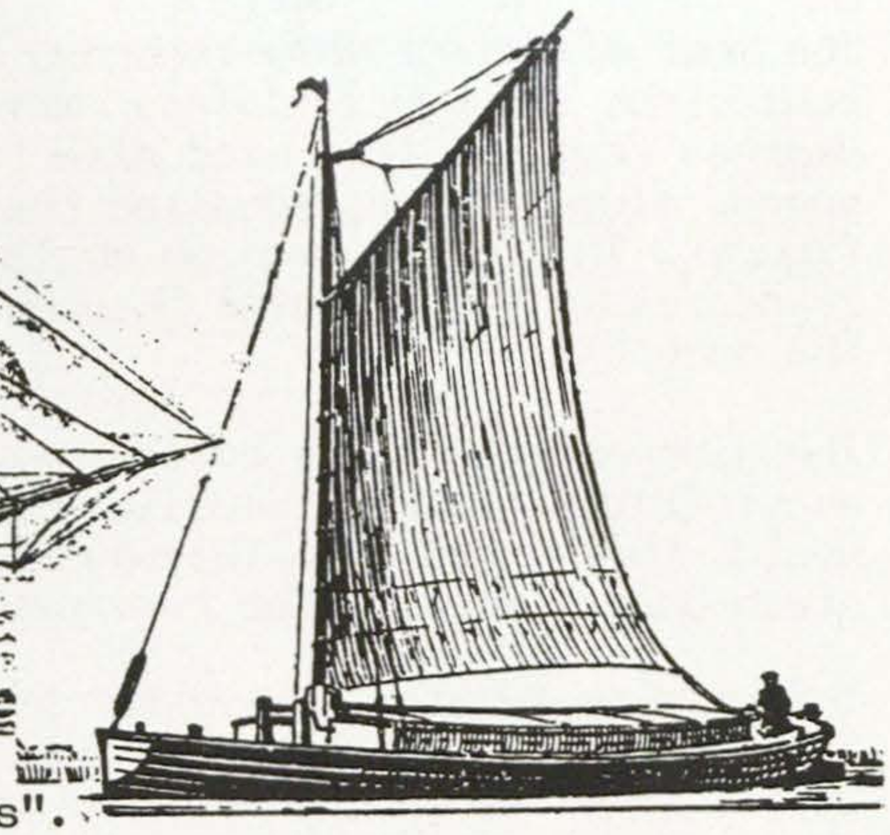
There must have been some terrible sailing disaster on the Nile about 2270 B.C. when the Old Kingdom broke up because, when authority again became established in the Middle Kingdom (2040-1780 B.C.) the hulls became round bottomed and they set a very low aspect ratio sail. This meant that they could no longer beat to windward. What they did instead was to run south up the Nile with the constant North wind behind them. Going north, they lowered their mast and sail and drifted down in the river current, as described by Herodotus.

The Ancient Egyptians thus invented or rather, perfected, the squaresail and the scow. The squaresail even persisted into the 20th Century in the Humber Keel. It used a leeboard and a wider beam and shallower draught. Mainly, however, for Mediterranean and North Sea sailors, the evolution took the form of a rounded hull with 'deadwood' aft to give lateral resistance. The sail was little altered. In this way, the ships of the Hanseatic League of mainly Germanic towns of Medieval times developed the 'Cog' and other ships which carried their extensive trade.

A Norfolk Wherry



"SIR LANCELOT."



From Basil Lubbock's "The China Clippers".

STEERING SAILS

From the above, it will be realised that the single ("Una") sail has always been recognised as the most efficient of all. However, the square rig is a nuisance to put about because the sail is aback when head to wind and both sheets and braces have to be trimmed quickly.

The Romans were the first to use a steering sail to speed up tacking. They set a small, fairly high aspect ratio squaresail in the extreme bow called the 'artemon'. On putting about, this came aback in the same way as does the jib of a modern yacht and pulled the bows across the wind for the new tack. But the square sail rig and the artemon disappeared with the end of the Roman Empire to be replaced by the lateen rig, introduced by the Arabs.

The people of north-west Europe did not accept the artemon on their ships until the 15th Century during which the artemon was re-introduced, followed by a lateen mizzen. Staysails which we would now call jibs also appeared in small craft in the 15th Century but these were not used in larger ships for 200 years.

At first the artemon was small but it slowly increased in size during the 15th and 16th Centuries and, like the mainsail became split up into three, the fore course, fore topsail and fore topgallant sail. When this happened, the sails on both masts began to function as a single aerofoil and another small squaresail was added forward to help during stays. To balance all this sail forward, an extra lateen was put on aft and a lateen topsail was sometimes added. These were eventually replaced by a single mizzen mast with squaresails, the lower course of which could not be made to draw when close-hauled. It was replaced by a gaff sail, the "Spanker"!

Finally, from about 1650 Onwards, staysails were run from the foremast to the bowsprit and a jib was set above them to a 'jiboom' or running extension to the bowsprit. The full rigged ship had appeared.

EFFICIENCY OF THE SHIP RIG

The most efficient ship recorded by Lubbock was the Thermopylae. She could tack through 10 points which means that she could sail 56 degrees from the true wind direction. I get the impression that her speed, close-hauled, equalled that of the true wind but I have no figures. This would mean an angle of sailing to the apparent wind of 28 degrees. This is worse than nearly all yachts- but quite good all the same.

The jibs and the sails on the mizzen mast allowed the ship to put about fairly quickly, usually with good weigh on. Only occasionally would they need to 'box-haul' which means that they made a stern-board, with rudder reversed.

The ship could also 'heave-to' by backing the sails on the mainmast. This stopped her and she lay quietly only making some leeway. This was useful in picking up a pilot or getting a tow line aboard.

THE INEFFICIENCIES

1. The straight yards were a loss of power, close-hauled, taking the flow out of the sails.

2. The gaps between the sails and the yard below were a loss of power and course to windward. Only one ship to my knowledge ever laced the feet of the sails to the yards below. That was the large German barque, the Preussen.

3. The sails on the foremast and mainmast acted like the genoa and mainsail of a sloop. The sail coefficient was reduced but pointing was only slightly reduced.

4. The jibs and sails on the mizzen mast were essentially steering sils and produced little drive, except with a quarterly wind. When windward ability was needed as in the ships bringing coal from Newcastle to London, the ship rig was not used. Instead the collier brig was developed which had no mizzen mast. They were powerful and weatherly.

5. The staysails between the masts seem to have been useless in adding to speed and were seldom used. The 'stunsails' (studding sails) which were additional sails set at the ends of yards were also reckoned to be virtually useless. In the figures which follow, I have ignored both

THE FIGURES

I have figures for only three commercial vessels:

1. Giralda, a Thames barge from "Uffa Fox's Second Book".

2. Gleaner, A Norfolk wherry from "Black Sailed Traders" by Roy Clark.

3. Sir Lancelot, a tea clipper launched in 1865 from "The China Clippers" by Basil Lubbock.

GIRALDA

L.O.A. 86 ft Oins. L.W.L. 85 ft Oins. Beam 18 ft 6ins. Draught (Laden) 5ft Oin. Sail area 3,000 sq.ft.(sprit rig). Displacement (laden) 150 tons, unladen 50 tons. These give the following figures to which I have added two lines assuming that the sail coefficient is 0.8 instead of 1.2 of the ordinary sloop. This reduces the effective sail area to 2,000 sq.ft.

Displ.	"L"	Sail area	L.D.R.	S.A./LXB	Br.No	Br.root"L"	P.N
50 tons	85ft	3,000sq.ft.	9.8	1.91	1.14	10.48	40
50 tons	85ft	2,000sq.ft.	9.8	1.27	0.92	8.55	50
150 tons		3,000sq.ft.	5.7	1.91	0.79	7.26	65
150 tons		2,000sq.ft.	5.7	1.27	0.64	5.93	81

The figures show that the unladen Giralda has the potentiality of being a very fast vessel. The J class yachts from the 1930's would seem to be only slightly faster. Shamrock V ("L" 90 ft.) had a Br.root "L" of 12.4 while Endeavour 1 ("L" 95 ft.) had one of 12.3.

Obviously, the speed will be reduced by cargo but the speed is still good in terms of yacht speeds.

The L.D.R. is good at 9.8 though still below the optimum of 11.0. The two J Class yachts above are, however, worse at 6.5 and 6.8.

The sail area/length X beam is interesting. We have shown an apparent optimum for this ratio of 1.5 or thereabouts for this figure. The figure for the barge using her whole 3,000 sq.ft. as a spritsail is 1.91. This is too large and obviously due to the inefficiency of the sails. If now, the figure is reduced to 1.5, the sail area becomes 2,353 sq.ft. instead of the 2,000 sq.ft. taken for its equivalent in the sloop rig using a sail coefficient of 0.8. One concludes from this that the efficiency of Giralda's rig is 0.94, in comparison to the 1.2 of the sloop rig.

GLEANER

Gleaner is the Norfolk wherry. L.O.A. is 57 feet. Beam 14 feet. Draught 3 feet to 4 feet. Displacement 16 tons and 41 tons with 25 tons of cargo. Sail area: 1,200 sq.ft. As will be seen, it is not necessary to assume that the loose-footed gaff sail is less efficient than the sloop rig.

The figures are as follows:-

Displ.	L.D.R.	S.A./L X B	Br.No.	Br. root L	P.N.
16 tons	9.5	1.5	1.05	7.93	60
41 tons	6.0	1.5	0.77	5.80	85

Like the Thames barge, the figures show a very fast vessel. I have been told that, in the pre 1939 regattas, the wherries were always faster than the yachts on a reaching or running course but not so fast to windward. The last remaining wherry, the Albion is under-canvassed. Again, the weight of the cargo slows the craft.

The L.D.R. is 9.5 (6.0 when laden). A good figure.
The sail area/length X beam is the optimum of 1.5, betraying no inefficiency of the sail.

SIR LANCELOT

Sir Lancelot is the only clipper ship for which Lubbock gives figures. She was launched in 1865, just after her more celebrated near-sister ship Aerial who won the 1866 tea race from China to London. The figures for both ships are about the same. The sail area is given in full but I only use the sum of the staysails before the foremast, the squaresails set on the three masts and the spanker or gaff sail on the mizzen mast. This ignores the staysails set between the masts, the studding sails and the fancy sails like Jimmy Greens. This is similar to ignoring the spinnakers of yachts.

The tonnage is a trouble as it is usually a figure of volume, not displacement. Moreover, two different figures are given, 1059 tons and 886 tons. Even the cargo's weight is in some difficulty. Aerial's load was 1,230,900 lbs. which is clear and is 549.5 tons of 2240 lbs. Sir Lancelot's cargo was 1430 'tons' The ballast of both ships was 100 tons of iron laid along the keelson with 20 tons of moveable ballast for trimming purposes. When laden with tea, 200 tons of washed shingle was also needed.

The figures for sail area are worked out for the 21,279 sq.ft. of plain sail which assumes a coefficient of 1.2 and for 8,866 sq.ft. which assumes a coefficient of 0.5. They give ratios for the sail area/length X beam of 3.2 and 1.34 respectively. The latter figure is too low, I think. A ratio for the S.A/L X B of 1.6 would be achieved by a sail coefficient of 0.6. This seems a better figure.

The figures are as follows:-

Length of keel and fore rake: 195 feet. Displacement ? 886 t.
Beam: 33 ft 9ins. Iron ballast: 120 tons Sand ballast 200 t.
Draught:(laden) 18 ft 8ins. Tea cargo: 549.5 tons
Sail area 21,279 sq.ft.

These give:-

Displ.	Sail Area	L.D.R.	SA/L X B	Br.	Br.root L	PN
1006 tons	21,279 sq.ft.	7.6	3.2	1.11	15.53	
1006 tons	8,866 sq.ft.	7.6	1.34	0.72	10.02	
1755.5 t.	21,279 sq.ft.	5.76	3.2	0.92	12.90	
1755.5 t.	8,866 sq.ft.	5.76	1.34	0.59	8.33	55

In general, the figures show a potential for very high sailing speeds which were not achieved. The average speeds of the best voyages to Australia from England work out at about 8 knots. Atlantic voyages from New York to England could get up to averages of about 9 knots while, in the reverse direction, they were reduced to about 7 knots due to the prevailing Westerly winds.

What clipper ships lacked for speed was an efficient sail rig and, as Thermopylae showed with her extra keel, some extra lateral resistance.

The America's Cup is raced for by 12 Metre yachts. These are very expensive toys which serve no purpose other than to enhance the prestige of the owners. Sir Thomas Lipton, for example, made a fortune from losing the cup some five times. The publicity allowed him to sell tea in the U.S.A. Nor are ballasted monohulls the supreme yachts which they once were. Catamarans and trimarans are faster.

It is suggested that the rules for the America's Cup be changed to produce cargo-carrying sailing yachts which could be scaled up to give sailing cargo-carrying ships. The following would be the basic rules :-

1. The 'sailing length' would be between 12 and 18 metres (39, 58 ft.)

2. Inside ballast of between 15 and 25 tonnes (of 2200lbs) would be carried.

3. Sail area to be 12 square metres (1284 sq.ft.)

These three rules would allow experimentation with beam, lateral resistance and sail rigs to be carried out. More rules than the above would be needed, of course, but that would be a matter for the pundits.

It is a matter of common observation that the yachting public becomes bored with any racing class after a time. People want change.I believe that the time has come to change the rules for the America's Cup.

SPEED TO SEAKINDLINESS YACHTS

In a seaway, some yachts throw their crews and loose items aboard about more than others. People cannot function well when they are treated thus. Nor can the yacht. In this section, we will examine what factors make for seakindliness and what the effect is, on speed.

Most of us will, at one time or another, have seen the short seas of a gale from a short fetch affecting yachts at moorings. If, as sometimes happens, the yachts should be lying beam-on to the sea, they will roll as each wave passes under them, some more than others. In one such gale, when I was watching a trimaran, some small ballasted monohulls would roll through 90 degrees i.e.,some 45 degrees each side of the vertical. In contrast, the trimaran I was watching only rolled some 10 degrees to each side. One could have slept aboard.

In the early 20th Century, before the advent of the engine for yachts, there was a fad for centreboard cruisers on the Eastern seaboard of America. They had shallow draught, inside ballast and a rounded hull with a lot of flare in the topsides.Even at 35 feet overall length and with a highly cambered cabin top, they did not have standing headroom. They are described as the "Presto" boats and were introduced by Ralph M. Munroe. They are described in a delightful little book "The Good Little Ship" by Vincent Gilpin (Livingstone Publishing Co.). The Presto boats were held up to be fast to leeward and to have seakindly motion, especially when hove-to with the board up. The shallow draught extended the number of harbours they could enter. Maurice Griffiths was the English designer of the type.

Two other types have a reputation for seakindliness. The twin bilge yachts are alleged to have an easier sea motion than deep keeled yachts. The Irish curragh is supposed to have survived gales in which plank built boats foundered.

The common factor in all these seakindly boats is shallow draught. The multihulls have it. So do the Presto boats, the twin bilge keelers and the curragh. To understand this, we have to make a study of waves.

THE NATURE OF SEA WAVES

I have read articles on sea waves -- and failed to understand them. They state that the particles of water in a wave move in a circle whose plane is vertical. At the top of the circle, where the crest of the wave is, the particles are moving downwind. At the bottom of the circle, where the trough is, the water particles are moving upwind. This would produce a sine-shaped wave in section. This theory does not fully accord with practical observation.

To observation, the water in waves moves towards the crests on both sides and away from the troughs. A buoy on the surface, for example, will move to windward as a wave approaches. As the crest passes it, it will surge to leeward and continue to do so until the trough comes along. It will then stop and move to windward again until the next crest comes along. The surge to leeward as the crest passes is always greater than any movement to windward. This is likely to be due to the wind blowing on the crest and explains the drift to leeward of the surface water of 1 to 2 or more knots produced by the wind. We are now in a position to understand seakindliness.

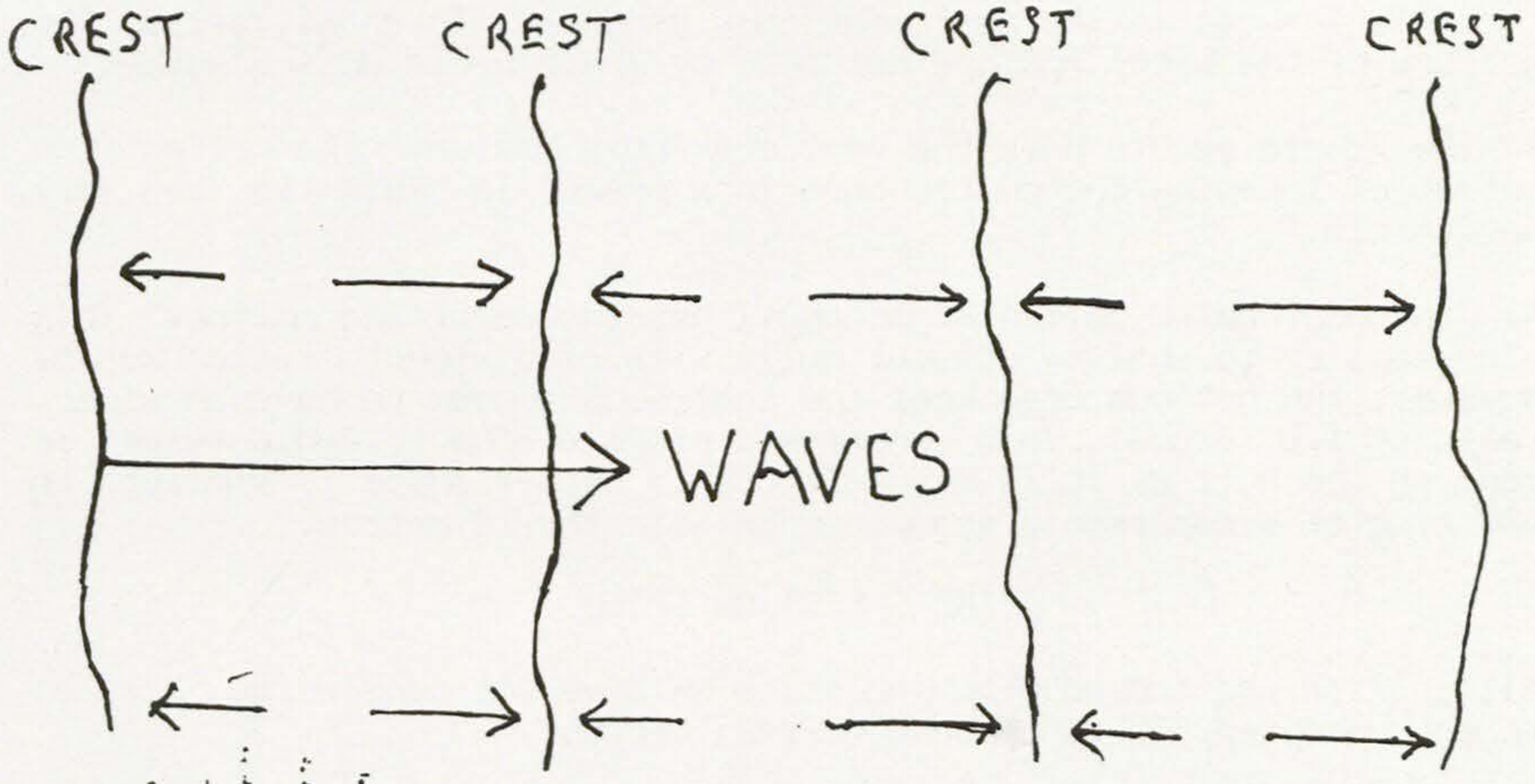
THE MOVEMENT OF YACHTS IN A SEAWAY

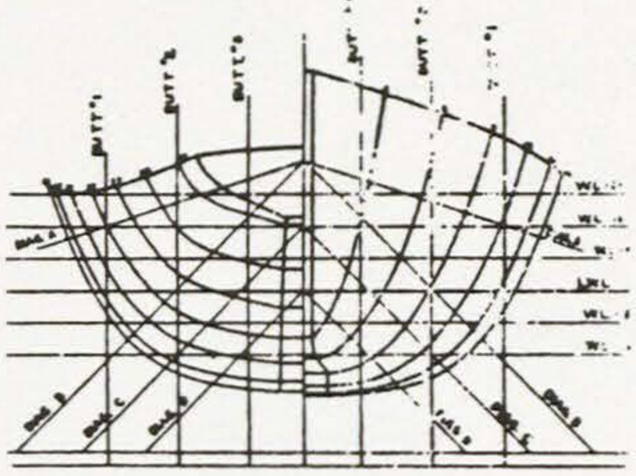
A yacht beam on to a sea, whether stationary or moving, will be pulled to windward as a wave approaches. The keel or centreboard will be in water which is relatively stationary and the yacht will have a heeling moment to windward.The heel of the keel yacht will be reduced if she is sailing. The multihull, by contrast, will profile the wave due to its stability and heel a bit to leeward. Due to the inertia of the weight of the yacht, both will appear to 'slide down' the wave to leeward.

When the crest of the wave comes along, the leeward- moving top water drives the hull to leeward and, if a keel or centreboard is in the deeper water, heel is exaggerated. The monohull may heel violently. The multihull will again profile the surface and stay more or less upright. The 'Presto' boats and the curragh without centreboards down, will also behave more comfortably than the deep keeled yachts.The surge of the hull to leeward will again be resisted by inertia and the keel or centreboard,if present. The yachts will appear to slide to windward.

In the leeward-moving water after the crest has passed, the hull is being pushed to leeward while a keel is being held in the deeper water. But the leeward movement is slowing down and the hull will slowly right itself to again be free from wave heeling at the trough of the wave.

The process is again repeated when the next wave comes along.

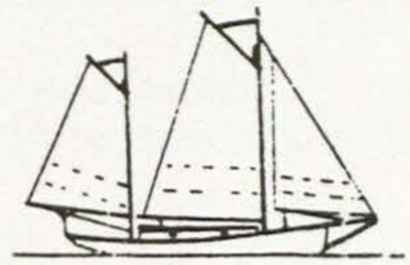




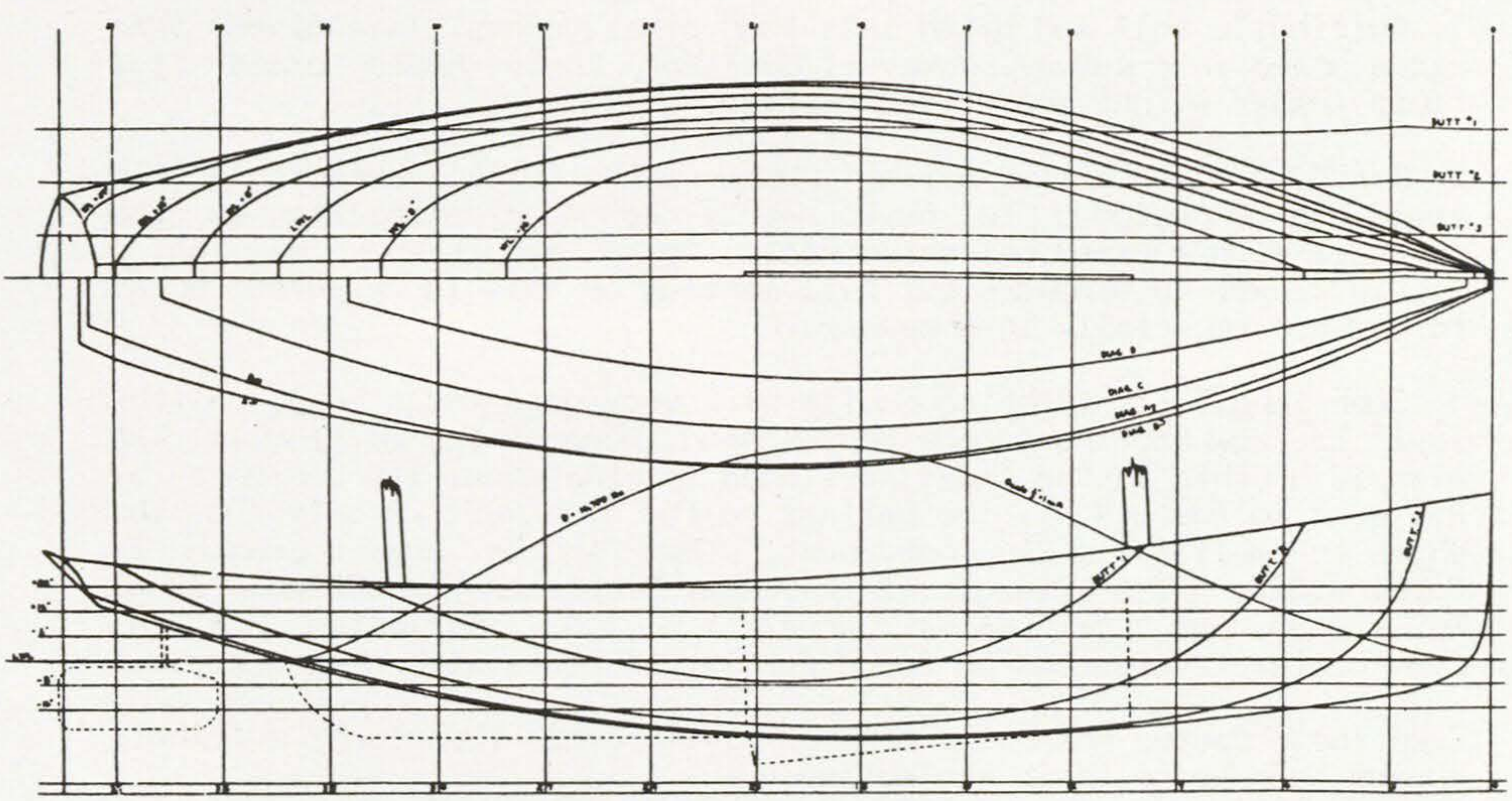
LINES OF THE KETCH,

"PRESTO"

DESIGNED BY COMMODORE MUNROE, 1888.



FROM JOHN GILPIN'S BOOK "THE GOOD LITTLE SHIP"



SUMMARY

1. The multihulls are the most seakindly yachts.

2. The curragh, a dinghy or 'sailer-trailer' yacht with fully retractable keel is the most seakindly monohull. These all sit on the surface of the water and are not held by their keels during waves.

3. The Presto yachts have the next seakindly motion. The effect on motion of lowering the centreboard in a seaway is said to be very noticeable.

4. The deep keeled ballasted monohull has the worst sea motion. This also applies to shallow draught hulls with high aspect ratio keels. However, the optimum deep keel and centreboard seem to have an aspect ratio of 1.0 (Bruce). This can have a profile of a triangle twice as long at the hull as it is deep although a better shape is similar to one wing of a supersonic aeroplane as with the 12 metres.

THE EFFECT ON SPEED

All rolling and indeed pitching which we have not considered has an effect on speed. It is reduced however because:-

1. It varies the angle of attack of the sails to the wind.

2. It makes the lateral resistance which is needed even on a beam course less efficient.

3. It varies the shape of the hull in the water which is usually rendered less than the best.

CONCLUSIONS

1. Multihulls roll and pitch less than other yachts. This gives them extra speed in a seaway. However, most of their speed comes from their lesser weight and wetted surface.

2. Boats of the 'trailer-sailer' shape with fully retractable fin keels can be designed to have nearly as much stability as the monohull with a fixed ballasted keel. As a result,they may be a little slower to windward but will make up or this in greater speed to leeward,especially in a seaway.

3. Some long, very light monohulls with very deep keels (e.g. Slithy Tove) are now getting speeds approaching those of the multihulls. An example of this is the 'box' sectioned International 110 designed by Ray Hunt in the U.S.A.. The ballast on the stub keel is only 300 lbs which is small for a 24 foot boat. The figures are:- Length 24 ft.0ins.Beam 4ft 2" Draught: 2 ft 9 ins. Displacement: 900lbs. Bruce No. 1.2 Br.root "L": 5.86 Sail area/L X B 1.67. Estimated P.N. 83 Even better figures can be found for larger boats with deeper keels.

Even these faster monohulls are not likely ever to reach multihull speeds because of their sea motion.

SPEED TO ACCOMMODATION RATIO

The ships of the Old Kingdom of Ancient Egypt (2770 to 2270 B.C.) were large hard chine scows for merchandise and round bilge, large paddling or rowing boats for the kings and officials. They were all decked and had large rectangular deck houses, made of light materials such as reeds on a wooden framework.

The Ancient Greeks largely seem to have used galleys with a sail for both merchandise and warfare. No accommodation is shown.

The Roman merchant ship was largely used to bring grain from Egypt to Rome. It was generally a tubby craft of round bilge construction with 'deadwood' aft driven by a single fairly high aspect ratio squaresail with the 'Artemon', a small squaresail, forward for manoeuvering. It had to be decked to keep the grain dry. The crew slept below decks.

In north-western Europe, no boats or ships seem to have been decked until Medieval times. The 60 foot bronze age boat, the curragh and the Viking Longships were all open boats. I have, however, found a reference to St. Brendan's curragh being '--decked on pillars'. This is a logical way to deck a curragh. Professor John O'Meara who must be considered the expert on the Brendan texts knows nothing of this reference and it may have come from some other source.

Modern yachts took their origin from the brigs and dispatch boats of the Navies of the world. All of them would have had accommodation below for the owner and crew. In the 19th Century,the yachts were large and the accommodation would not have hindered the performance much. During the last 100 years, however, the yachts have been becoming smaller and accommodation harder to fit.

At first, cabin tops were added to give standing headroom. Berths were put at the sides of the cabin and a small galley and heads gave the boat basic comforts. The Folkboat is a good example of his.

Finally, it was realised that boats with a large beam and the sail area to go with it were fast. The beam to length ratio rose to 1:3 and very good accommodation could now be fitted such as six berths and full standing headroom on a 25 foot yacht.

THE EFFECT ON SPEED.

All accommodation must reduce speed by its weight and windage, if there is a deck house or extra freeboard. For speed, therefore, the weight and windage of the accommodation must be kept as small as possible. No way to reduce this to figures is seen.

ACCOMMODATION IN MULTIHULLS.

The long narrow hulls, if above 35 feet in length, can give berths, galley and heads in a catamaran. With a small cabin between the hulls, this can be very tolerable. Small trimarans such as Arthur Piver's Nugget, and others, put the berths out over the water, in this way adding to the strength of the cross beams and giving a spacious feeling.This adds to windage. Modern practice is to keep the accommodation within the main hull, as far as possible.

BOAT SPEED TO WIND SPEED RATIO

This is the ultimate test of a sailing boat's efficiency. It is therefore right that the A.Y.R.S. gives a prize for it at the Weymouth speed trials. For full evaluation it is necessary to give the figures for speed ratios for several courses, namely:-

1. Directly to windward, including one tack.

2. On a close-hauled course at the best velocity made good to windward.

3. At the yacht's highest speed which occurs with the true wind direction just aft of the beam.

4. On a running course, dead downwind.

5. Tacking down wind as in ice yachts and very fast craft.

This ratio is hard to measure because of the fluctuating nature of the natural wind which is continually varying both in speed and direction. I can think of no means of recording fluctuations of the wind direction but the average windspeed can be got by a revolving cup anemometer whose revolutions are counted electronically. For a single boat, there should be some 'stopwatch' mechanism to reduce the dial to zero for the start and to stop the counting when the run is finished. When many boats are being measured a continious record with a marking device to record when boats start and finish would be the only way.

Some sophisticated yacht instrumentations give the apparent wind's direction and speed as well as the boat's speed. From these, the boat speed to the true wind-speed can be calculated. To be optimum, however, the windspeed and boat speed would have to be averaged over the length of the run. These averagings could be done electronically in the instrumentation or with a separate averaging device for which the recording would be by human 'dial watchers'.

With appropriate instrumentation and measurement of a yacht's speeds on various courses to the true windspeed, polar curves can be drawn giving the full performance in a readily understood manner. Usually, wind speeds of 5, 10, 15 and 20 knots are used. The A.Y.R.S. has blank polar curve sheets for the use of yachtsmen.

PRESENT INFORMATION

The scientific study of yachts and their performance reduction to a set of figures or polar curves is undertaken by few people. This is largely due to inadequate instrumentation which will be rectified in the course of time. The only figures which I can now give are mostly approximations but they can be a guide for future work. They are all for broad reaching.

1. The sailboards measured at Weymouth for the A.Y.R.S. prize went at 1.4 times the speed of the wind. This took place in strong winds. A more useful figure would have been the boat speed to true windspeed in light winds.

2. The Tornado catamaran is alleged to go at a top speed of about 2.0 times the true windspeed. Her Bruce number was stated to be 1.9. This led to the tentative conclusion that the fastest speed of a yacht is close to its Bruce Number. From my figures, and adding 360 lbs of crew weight, the Bruce number is 1.72 which would need a reduction of the Bruce No. by 0.86 to give the figure of 2.0. If, on the other hand, we use the Br. root L as the better index of boat speed, we have a figure for the Tornado of 7.50. This needs to be divided by 3.75 to give the figure of 2.0.

3. In the account of the modern C Class catamarans, given earlier in this writing the maximum speed on a beam reach was 2.5 times the true windspeed. The Bruce number was 1.8 and the Br. root L was 9.0. Here, the 'Speed ratio' is given by dividing the Br. root L by 3.6.

Tabulating these three boats, we get:-

	Bruce Number	Br.root"L".	Speed Ratio.	Br.root L/SR
C Class	1.8	9.0	2.5	3.6
Tornado	1.72	7.5	2.0	3.75
Surfboard	1.9	6.57	1.4	4.7

Of these three, only the speed ratio of the surfboard was at all accurately measured. The speeds of the other two are estimates or casually measured at best.

CONCLUSION

Speed ratios for a broad reach have not been taken enough to come to a better conclusion than that they lie between 1/3.6 and 1/4.7 of the Br. root "L". Speed ratios for the courses to windward, close-hauled and running are not known to me. That on the dead run will, of course, be less than 1.0. With a full set of polar curves, the course and speed to get directly down wind by tacking in ice yachts and very fast craft can be discovered.

SPEEDS IN VERY LIGHT WNDS

Almost the total hull resistance when a yacht is moving slowly comes from skin friction. This holds true up to a speed of about 0.7 of the square root of the waterline length in feet. Wave-making is not important until one exceeds the 0.7 ratio. For these reasons, I guess that the derivation of the Portsmouth Yardstick numbers has been mostly in light winds. Therefore, I think that the relative speeds of yachts in very light winds is still given by the Br. X root "L".

The procedure for moving in very light winds is therefore:

1. Have a very clean and smooth bottom.
2. Have a high value for the Br. root "L" formula.
3. Heel the boat to leeward to make the sails take up their shape, if they are not fully battened. This can also reduce the wetted surface in some shallow craft.
4. Don't rock the boat.

The trimaran and Melagasy outrigger have an advantage over all other yachts in very light winds because they reduce their wetted surfaces as they become more upight. When sailed thus, almost their total resistance come from the single, low wetted surface hull in the water. They should also be designed to heel slightly to leeward in light winds with only the slightest area of the lee float touching the surface. This will let the soft sails pull more effectively.

AERODYNAMICS

There are certain hints that the wind at 1, 2 or 3 knots behaves in a different way to its behaviour at 10 knots, for example.

1. Dinghies are advised to sail freer in light airs. This could be because the wind can be turbulated more easily.

2. The wind, blowing over the surface of a smooth and calm sea will be more fixed in strength and direction than if it blows over sea waves.

3. The model glider and aeroplane makers state that wing chords under 3 inches are not aerodynamically efficient. I know of no explanation for this.

BALLASTED MONOHULLS

Some monohulls with all their ballast at the end of a keel are good in very light airs. The Six Metre Class for example has 75% of their total weight as ballast. This allows them to have lots of sail area in relation to their wetted surface.

ICE YACHTS

Ice yachts will not move in windspeeds of 1 or 2 knots. This is because what is called 'Static' friction or the pull needed to get a body sliding from stationary is greater than 'Dynamic' friction or the pull needed to keep a moving body sliding. Dick Andrews tells me that the procedure is then to run along pushing the yacht up to a speed of 3 or 4 knots before getting aboard and trimming the sails. This is done on a beam course. Once moving, the yacht will speed up to go at from 5 to 10 knots. Ice yachts sail at a speed ratio of 5 to 7 times the true windspeed. They thus get the benefit of a large apparent windspeed. This, in turn, allows them to turn far more of the wind's mass by the sails and thus get more power.

CONCLUSION

A yacht's speed in very light winds depends entirely on the ratio of the sail area to the wetted surface. Increasing the sail force coefficient has the same effect.

AVERAGE OCEAN SPEEDS.

When crossing the ocean where the winds will be variable in strength and direction, it is the AVERAGE speed which will be important.

Many yachts have crossed the North Atlantic ocean in the trade wind belt at an average speed which works out at the square root of their waterline length in feet. This must be nearly as fast as any yacht can attain as an average. Fewer yachts can do the same average speed crossing the North Atlantic from America to Europe because the winds are much more variable.

Voyages from Europe to America in the North Atlantic in the prevailing Westerlies have to sail close-hauled most of the time and hence speeds are low. It seems truly remarkable that so many yachts can do the 3,000 miles in 30 days, an average of 100 miles per day.

Voyages from England to Australia are totally different fom Atlantic voyages. The doldrums of the equator have to be passed and the "Azores high pressure area" which once captured sailing ships for as much as six weeks has to be crossed. The record for this voyage by a clipper ship gives an average speed of 8 knots. The usual average was 6 knots while 4 knots was common. As a rule, an average distance of 100 nautical miles in a day's work was considered satisfactory by both clipper ships and yachtsmen.

Lubbock in his book "The Colonial Clippers" gives the length of time spent in the various conditions as follows:-

One third of the time the winds were strong and favourable.
One third of the time had head winds.
One third of the time had calms.

INCREASING SPEEDS OF YACHTS ON VOYAGES.

The only ways to incease the average speed with quarterly winds are

1. Have a larger Br. root "L".
2. Use a multihull, preferably a catamaran.
3. Increase the sail force coefficient.

With the true wind on the beam, one can increase speeds as above but with a very fast yacht, one can run up against what Walter Bloemhard called "The apparent wind barrier". This consists of the fact that the apparent wind moves forward due to the boat speed. The following table shows the beta angle (course made good to the apparent wind) for various 'speed ratios' in a beam wind:-

Speed ratio	Beta angle degrees
1.5	56
2.0	27
2.5	22
3.0	18
5.0	11
7.0	8

MEDIUM WINDS.

Owing to the high 'speed ratio' or boat's speed to true wind speed, trimarans often sail in strong apparent winds when the wind blows from 7 to 15 knots. This means that the float will be carrying a great deal of sail pressure and will need to be designed for minimum resistance at a high relative speed. This requires a lot of length and a length to beam ratio of 16 to 1 if the sections are semi-circles or an L.D.R. of the same figures if they are not, as shown by Edmond Bruce.

STRONG WINDS.

In wind speeds of 15 knots upwards, boat speeds are not greatly increased except when broad reaching. However, the float is well pressed down into the water and its buoyancy starts to exert a marked effect. To counter the 'bows down' effect of the sails on a broad reach, it should be placed further forward than is required to take the capsizing moment of the sails when close hauled. This then lifts the bows appropriately. It also moves the centre of lateral resistance of the hulls further forward and an extra centreboard aft has been used to give sail balance and remove weather helm.

Soft sails can probably take 22 degrees of beta angle and thus can only produce a speed ratio of 2.5 in a beam wind. The ice yacht rig of fully battened, high aspect ratio sail with a revolving mast which is slightly bent with a hollow to windward is necessary for speed ratios of 5.0 and 7.0. The compound aerofoils of the C Class catamarans are similar in effectiveness. The lowness of the sail's 'drag angle' is at least as important as the sail area. The mast length of the C Class is limited to 40 feet. If this had not been so, I think we could well have seen ice yacht rigs being used on them instead of the aerofoils.

Increasing speeds to windward is very much more difficult because one runs up against the 'apparent wind barrier' nearly all the time. A boat, for example, sailing at four points (45 degrees) from the true wind and making a V/mg (speed directly to windward) of half the true windspeed will be sailing at a beta of 18 degrees, a very close course to the apparent wind. Indeed, I would say that it is at the limit of the performance of soft sails if it has not gone beyond it. The Una rig of fully battened high aspect ratio sail can take a beta angle of 8 degrees, as we have shown. It would increase speed and also allow the boat to point higher to the wind. There is no doubt that the windward performance of the una rig explains its value in the earlier figure study, although it has advantages on other courses.

Very fast catamarans and trimarans should all use the una rig for best average speeds. The early objection to the rig of having the mast further forward, thus inceasing pitching is not so relevant nowadays with light alloy masts. Other options are 'over the top' aerofoils and C Class type aerofoils. The rig should most certainly be used in the Trans-Atlantic races from Plymouth, England to Newport, Rhode Island but has not, so far, been tried.

Speeds in very light winds are proportional to the sail area to wetted surface ratio. In practice, this closely approximates to the Br. X root "L" figures. On the analogy to the method used for getting ice yachts going in very light airs, rowing the yacht from the lee side might be disproportionately useful. The trimarans will be faster in light going than the catamaran.

CONCLUSION.

The average speed when crossing an ocean can be increased by increasing speeds in head winds and in light winds. The requirements are as follows :-

1. Have a large Br. root "L".
2. Use a trimaran.
3. Set a fully battened, high aspect ratio una sail on a turning, bendy mast.
4. Row in very light going.

OPTIMUM TRIMARAN FLOATS.

My opinion is that, in the long run, the 'sailing surfboard floats' of the Melagasy outrigger will prove to be the most efficient for the trimaran. This has yet to be proved. In the meantime, floats are being used and should be studied.

The basic purpose of trimaran floats is to stabilise the main hull against heeling and 'bows down' pitching force of the sails for various wind strengths and directions.

LIGHT WINDS

This is where the trimaran is faster than all other sailing yachts, including catamarans. The water resistance comes almost totally from the main hull, the float just touching the water surface. The resistance will, however, be totally due to wetted surface and this should be minimised in the float.

The section should be nearly a V at the bottom but rounding it will reduce resistance. The immersed waterline length should be short. A float W.L. length of 4 feet would suit 3 knots of boat speed; 16 feet wold suit 6 knots while 25 feet would be appropiate for 7 to 10 knots. To accommodate these various waterline lengths, the profile of the bottom needs to be well rounded. Dick Newick is the only designer to use this with his 'banana float shape' but he lives in a light wind area. European designers do not round the profiles of their floats as much as he does.

SUMMARY

At minimum immersion, the underwater float should have rounded V's on a short waterline. Above this, there should be long overhangs, V'd forward and a counter-shape aft, developing quickly to give the extra waterline length and an L.D.R. of 16 or more. At full immersion, the centre of buoyancy should move forward.

The total buoyancy of the float seems to be about 150% of the total weight. There is no place for anything but the smallest transom on the counter.

POSTSCRIPT.

When I was a young man, the "Way of a ship at sea" was a great mystery. In 1950, only a few people understood how and why a boat could sail to windward. There was a correspondence in the yachting magazines to prove this. Yachts were designed by 'rule of thumb' with little or no insight into their design.

It was in the interests of professional yacht designers to keep up the idea that yachts were beyond the comprehension of ordinary yachtsmen. This is a bit odd because the only school of yacht design of which I know is the Westlawn Correspondence course in the United States. One could say that most professional yacht designers are unqualified amateurs who can draw a good enough set of lines to please amateur yachtsmen. Only a very few can make a living from it without also having a yard to build the boats.

Through the years, the A.Y.R.S. has stubbornly resisted attempts to have the word "Amateur" dropped from its title. This is because professionals, even if they have tank tested designs at the expense of their customers, do not publish their findings. Nor do many academic institutions, to their shame. Professor Bradfield is a notable exception.

It is hard to see what professionals hope to get from our dropping the word 'Amateur'. They may hope that we will commission designs from them or employ them as 'observers' at experiments. The defunct Yacht Research Council spent some £10,000 from 1954 onwards to produce the single figure for the coefficient of the sloop rig on a Six Metre yacht as 1.2. It was the sterile methods they employed which led me to start the A.Y.R.S.

The A.Y.R.S. book "Design for Fast Sailing" by Edmond Bruce and Harry Morss and this publication "Optimum Yachts" are typical amateur effort. Neither would, or indeed could, have been produced by professionals who, if they had had the information, would not have published it.

Every yachtsman should know what kind of yacht he wants and can afford. It is hoped that this publication will guide him in his selection of his "Optimum Yacht".

GLOSSARY (By R.M.Ellison)

ASPECT RATIO. Sail = height of luff (leading edge) divided by the length of the foot. Keel, centreboard or rudder depth divided by the length at join to hull.

β BETA = Angle between course and apparent wind. John uses 'Beta Angle' to indicate course made good to windward in the text.

BR.N. BRUCE NUMBER = Square root of sail area divided by cube root of displacement. The higher the number the better the 'power to weight'.

CLEW = Aft lower corner of a sail where foot & leech join.

DRAG ANGLE = Angle whose cotangent is 'Lift to Drag' ratio. A small drag angle has a high lift to drag ratio indicating good windward ability.

FOOT = Lower edge of a sail joining tack to clew. "Loose footed" means not secured or laced to a boom.

λ LEEWAY ANGLE (Greek Lambda λ) = Angle between the boats heading and the course made good if there is no tide or stream.

L. LENGTH = John used mean between length overall (L.O.A.) and the waterline length at rest (L.W.L.) for his calculations as this will be the approximate sailing waterline length of many yachts.

LDR. LENGTH TO DISPLACEMENT RATIO. A fineness or length to beam ratio important when considering resistance due to waves made by the hull.

LUFF = Leading edge of a sail joining the tack to the head.

PC. PRISMATIC COEFICIENT = The volume of a hull as a % of a 'box' having the same length, bredth and depth.

PN. PORTSMOUTH NUMBER = Handicap system giving a time allowance based on actual race results. For popular classes that often race together this gives a very good indication of performance.

SAIL BATTEN = A wood, plastic or composite strip inserted into a pocket on a sail. Many monohull class rules only allow short battens to hold the leech of the sail flat. High performance craft and cruisers can use full length battens which hold a sail to a chosen aerofoil shape and prevent it from flogging when the sheet is released

SAIL FLOW = The depth of curve as seen from above or below. 1:6 or 1:8 refers to the deflection from a flat compared to the horizantal length of the sail. On a loose footed sail it could be the amount the sail curves to leeward of a straight boom.

SAIL TWIST = The amount the head or peak of a sail sags to leeward compared to the angle of the boom or foot to the fore and aft line of the craft. The upper part of a sail can not drive to windward if there is significant twist. Very common with old or worn sails.

UNA RIG = A sailing craft having only a single sail.

WISHBONE BOOM = Developed by past AYRS President Lord Riverdale the sail sets between two parts of a boom which are joined at the mast and clew. The boom slopes downwards from the mast and the foot rises from tack to clew forming a 'kicking strap'. The slope of the boom keeps the leech in tension removing twist. The sheet is only used to position the boom. Flow or camber of the sail can be controled.

DR JOHN MORWOOD

Reprinted from the obituary column of the 'Times' newspaper 15th January 1987 with permission

Dr. John Morwood who died on December 28 at the age of 71, was known throughout the world as the founder of the Amateur Yacht Research Society, which encourages innovators in yacht design to exchange their ideas.

His approach, as editor of the society's journal for many years, contributed significantly to the development of the modern catamaran and trimaran by the great multi-hull designers.

And many other innovations, hydrofoils, self-steering gear and the controversial winged keel, owe much to his interest and determination to have the technical problems aired in his columns.

An Ulsterman, born in India, on September 10, 1915, Morwood went to Belfast Medical School, qualifying just in time to join 124 Fighter Squadron as medical officer during the Battle of Britain. He served as MO to RAF squadrons for the rest of the war.

Afterwards he set up in general practice in Folkestone, and founded the Amateur Yacht Research Society in 1955. He was its editor, then consulting editor, until his death.

He developed the work of the society by encouraging innovators to write to him about their ideas which he published in *Amateur Yacht Research Society,* its quarterly magazine.

Besides multi-hulled yachts, the development of the sail-board in this country was quite positively due to his publishing details in 1966. He also gave encouragement to hydrofoil stabilisation, developed by Edmund Bruce and Henry Morse in the USA.

Many of these ideas seemed crazy on paper but their worth was often proved in practice at the annual Portland Sailing Speed Week. At one of these the world sailing speed record was broken and held for many years by the twin-hulled British yachts, *Crossbow I* and *II,* based on principles to which Morwood had given his support.

When this record was finally broken, in July last year, at the remarkable speed of 38.86 knots, it was by a sailboard, for which some of the credit, too, must be his.

An alert man with more than a hint of mischief about him, Morwood was an ideal character to be in charge of discussing technical innovations. He loved controversy, and his polemical personality was reflected in the vitality of *Amateur Yacht Research Society's* pages.

Outside surgery hours he often worked late into the night on the affairs of the society, and with his Irish charm, sometimes persuaded patients to help him in its administrative and secretarial work.

He leaves a widow, Pat, and three daughters.