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SAILING FACTS and FIGURES

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Administration and Membership:
Michael Ellison, A.Y.R.S., Hermitage,
Newbury, Berkshire, England, RG16 9RW.

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SAILING FACTS AND FIGURES

INTRODUCTION

This publication is mostly a picture book. To many people, the pictures will be self-explanatory but, for others, some explanation may be needed. A few drawings, graphs or diagrams may need to be studied for an hour or more to achieve a full appreciation of the information they contain.

The general line of the theme is to give a rather unusual view of the theory of sailing for a start, following this up with facts and figures about some well known (and some less well known) boats. Finally, the essential features for designing a fast boat are put into practical expression in the form of a mono-hull boat which I call 'Sawsbrulder'. Multihull enthusiasts will find that Dick Newick's 'Val' trimaran design has the same features.

THE DRAWINGS

The wind blows upon the sails of a boat and is turned from its path by an angle called 'downwash' by the aeroplane people. Yachting folk might call it 'weatherwash.' The streamlines shown are more crowded together on the lee side of the sails, indicating that the air speeds up there. This speeding up of the wind, creates forces on the lee sides of the sails while the slowing of the wind on the weather side also creates forces. These forces everywhere act at right angles to the sail.

Fig. 2 shows all these forces and how they act. Fig. 3 adds all these forces together and portrays them as an imaginary rope pulling the boat mostly sideways but a bit forwards on the close-hauled course. Another way of thinking about the creation of this force is to think that it comes from turning the air from its direction to make the 'weatherwash' because the air has weight. The 'Resultant Sail Force' acts at an angle aft of a right angle to the apparent wind direction. This angle is called the 'Sail Drag Angle' (δ_S).

Fig. 4 shows a boat being pulled along a canal by a man. A rope is tied to the lee gunwhale and is being pulled in the same direction as that produced by the 'Resultant Sail Force.' A keel or centreboard is shown on the boat which prevents it moving towards the man. Instead it moves along the canal, making an angle of leeway which we call lamda (λ). The 'Resultant Hull Force' exactly equals the pull by the rope and, like the resultant sail force, acts aft of a right angle to the water flow or 'Course made good' by what we call the 'Hull drag angle' (δ_H).

Fig. 5 is the 'Sailing diagram.' The 'Apparent wind' strikes the sail at an angle (β) from the course made good and produces Fs the resultant sail force. This is exactly equalled by F_H, the resultant hull force. The boat makes an angle of leeway (λ) which has to be added to the heading to get the β angle.

Fig. 6 proves the 'Course Theorem' which states: "On any heading, the course made good is equal to the sum of the drag angle of the sails (and hull windage) and the drag angle of the hull in the water (including parasitic drags of all kinds).

Fig. 7 is the 'Sailing Triangle' which is what is called a 'Vector diagram.' It shows the relative directions and velocities of V_T, the true wind, V_A the apparent wind, V_B the boat's speed and V_{MG} the 'Velocity' made good directly to windward. Gamma (γ) is the boat's course to the true wind.

Fig. 8 is a concept of 'The Theoretical Yacht' which is a perfect sail in the air and a perfect keel in the water without a floating hull being present–or any means of stability. The sail is in contact with the water surface, is thin and fully battened. I think the hydrofoil should be related in plan form to the surface waves it produces, though no studies confirm this.

Fig. 9 shows the losses from the sloop rig in comparison with theoretical perfection. My readers will immediately add up these losses and find they come to 88%. My guesses of the amounts of loss may therefore be wrong or alternatively, they may not add up numerically. However, a 'Sail Force Coefficient' (Cs) in excess of 2.0 can be achieved by a solid compound aerofoil (Patient Lady). The best I have found is 4.4 in the aerofoil literature and the Flettner Rotor achieves 9.0. Most good sloops have a Sail Force Coefficient of about 1.2 which is that of a flat plate while the junk rig seems to be in the region of 0.8.

Fig. 10 is a reminder that aerodynamics is totally different at windspeeds below 14 knots. Probably the lift forces do not change much if at all, but the drag certainly does, as shown in the graph. This also teaches us to beware of using bare round poles without sail being set on them. Thin aerofoils (sails) seem best at low wind speeds such as used by Aquarius V in the 1976 'Little America's Cup.' Miss Nylex, whom she beat was better in winds over 14 knots. She has a thick aerofoil with flap. The Flettner Rotor yacht was also poor in winds less than 14 knots.

Fig. 11 scans the subject of "HYDROFOILS" used either as such or as centreboards and fin keels. Nearly all such are of low aspect ratio, 1.0 or less. This means to me that they are not true hydrofoils but function as 'fences.' The forces they produce are due to water being shoved up on the lee side. A corresponding hollow is to weather. If a fin makes surface waves, I think its plan shape should be related to the wave shape produced such as the versed sine-trochoid curves advocated by a previous generation of yacht designers for sectional areas. The 'Square Meter' Scandinavian yachts used this shape for fin and rudder and they are certainly fast. A side effect is a higher centre of lateral resistance.

Fig. 12 gives the symbols for various angles, speeds, etc., used by the A.Y.R.S. There are at least four other systems of symbols with some items the same as ours. Others are different. I seem to have ommitted to put in α which is the angle of attack of the wind on the sails. Owing to the sails being twisted, this angle cannot be measured but the angle between the apparent wind direction and the boom has been called α by some people (Edmond Bruce).

Figs. 13, 14, 15 and 16 gives the figures taken of four yachts. Those for the 'Val' trimaran, measured by Harry Morss show that it is the most efficient sailing yacht in the world. C and D Class catamarans may be faster but this is due to their having relatively more sail area.

Fig. 17 gives what performance figures we have for an ice yacht which are truly remarkable.

DESIGNING SAWSBRULDER

There is little point in making a study of any subject unless it can be put to some use. All the facts and figures which have been given, with any new information I can rake up will now be assembled to see if a single hulled yacht can be devised with the performance of Dick Newick's 'Val' trimaran.

Three figures seem to be of incisive importance. These are:–

1. The sail Area to Wetted Surface ratio (S.A./W.S.). This decrees the speed in light winds where the boat is going more slowly than a V/Square root L of 0.7. If this ratio is 3.0 or more, the boat will be a good 'Drifter.'

2. The Bruce Number (Br.). This is Sail Area$^{1/2}$/Displacement$^{1/3}$. I hope to show that the speeds of boats around an average racing course are directly proportional to Br.

3. The L.D.R. is the Length to Displacement ratio which, by a rather complicated formula, is approximately the length to beam ratio for a catamaran hull. If hulls are too long and skinny, there is too much wetted surface but the wave-making resistance is low. If hulls are too short and fat, there is too much wave-making resistance and even water turbulence aft but the wetted surface is low. One would therefore expect an optimum ratio for this, which I think is 11.0.

Fig. 19 shows how in Light winds the boat speed (V_B) is proportional to the apparent wind speed and the square root of the sail area. F_S is the sail force. F_H is the hull force. V_A is the apparent wind speed and A_S is the sail area.

Fig. 20 is a graph of boat's speeds against the square roots of their waterline lengths. The dotted line is the mean of the boats while the solid line is drawn to show where the boats mean would be if they sailed at speeds proportional to the square roots of their lengths. My conclusions are given in Fig. 21. The only item which needs explanation is the term 'Wind Scaling'. I use the term for the fact that larger boats can set relatively more sail area than small ones because their stability is relatively greater. Edmond Bruce set out the principle of scaling as follows:–

Large boats will behave exactly as do their models at all smaller sizes if:

1. All linear dimensions are accurately scaled. This means that sail area will be proportional to the square of the scaling factor, as will the wetted surface while the displacement will be proportional to the cube of the scaling factor.
2. All speeds and velocities are scaled in proportion to the square root of the scaling factor. This means that the boat speed expected will be proportional to the square root of the scaling factor IF THE WINDSPEED IS SIMILARLY SCALED. This means that large boats are sailing in winds which are relatively lighter than small boats.

Fig. 22 is a graph of speed and Bruce Number. The heavy lines all radiate from the point where Br is 0.0 but their positions have no significance. Fig. 23 gives my conclusions. Heavy and ballasted boats are favoured by this evaluation so it could not, on its own, be used as a rating rule.

Fig. 24 is the speed and L.D.R. graph of the 29 dinghies and 4 keelboats which did best on the previous two graphs. It would appear that there is an optimum of 11.0 for all Bruce Numbers. If the L.D.R. is much below this, speeds are badly affected. I am a little surprised that the optima are not more clearly shown, however.

Fig. 25 describes the ten best dinghies from the first two graphs in terms of Br. L.D.R., whether the bilge is round or chined, whether they use spinnakers and trapezes or sliding seats and the rig. As could be expected, the bigger boats have bigger Bruce Numbers. The L.D.R. while varying from 8.4 to 16.5 averages at, guess it, 11.0. Four boats have chines while 6 boats are round bilged.Six boats use spinnakers while four boats do not. This shows the spinnaker as of little value. By contrast, all boats use trapezes or sliding seat except the Una rigged boats. Finally, there are three Una rigged boats among these ten which is far more than their proportion in all the dinghies. It would appear that the Una rig is likely to be faster than the sloop.

THE DESIGN

Armed with all this information and the knowledge that I am not likely to improve on some existing design somewhere, I hunted through my library for boats which either met or could be made to meet the better figures. Four designs are shown, Black Soo and the New Haven Sharpie, both of which have been claimed to have sailed at 20 knots. The Freedom 40 for a version of the Una rig, though on two masts and finally, the 'Skipjack' or 'Bateau' Messenger which was designed for illegal purposes and therefore speed. Both the New Haven Sharpie and the Skipjack can be capsized.

THE HULL
Of these four boats, I chose the skipjack Messenger as my model. I kept the beam of 10 feet but lengthened the hull to 46 feet overall and 44 feet on the waterline. I also raised the topsides to give 6ft. 6ins. headroom at maximum and 6 feet minimum headroom.

THE KEEL
To prevent capsize, a ballasted fin was added which could be raised hydraulically with a slot wide enough to accommodate the ballast. This slot would have to be plugged to steady the fin when it was working. The wide slot can also be used to accommodate an electric 'Outboard' motor whose current would come from a generator of appropriate power, thus, only one motor need be on board.

The fin profile is that of my beloved 'versed sine-trochoid' shape as is the skeg-rudder combination, though the rudder trochoid is turned upside down. The skeg-rudder is on hinges at the top and fits into slots on the transom and the hull bottom. Thus, with keel and the skeg-rudder retracted, the draft is reduced to 18 inches.

THE COCKPIT
Yachts are used in three ways, Firstly, they can cross oceans. Secondly, they can do some longshore cruising with an occasional hop across a channel to offshore islands or continents. Thirdly, they can sit in Marinas or docks and never put to sea except for an occasional trip under motor.

Ocean racing or cruising yachts should not have cockpits. Nor need the Marina yacht have one. Sawsbrulder's hull is therefore totally filled with the accommodation and the cockpit is placed on deck between the masts with three forward-facing seats covered with clear plastic windscreen and top. Aft of this are two side benches with lockers under them. In harbour, the whole cockpit can be covered by a tent giving full headroom. At sea, a canvas cover can keep out wind from aft. I would hope to have the generator in one of the cockpit lockers.

THE SAIL RIG
This consists of two semi-elliptical sails, of unequal sizes to prevent the addition of the wing-tip eddies. The larger sail is forward so I suppose it could be called a ketch rig. However, only being a two-sail rig, it has none of the aerodynamic faults of the usual ketch, I believe that it will be very powerful with a Cs in excess of 2.0 – and very close-winded to boot.

The masts have no stays and are made from I-shaped sectioned extrusions, streamlined a bit with foam. The wire spans on the curved yards run in sliders which, in turn run up and down the mast on a cross bit of the I section.

I have no idea how the semi-elliptical sail can be best worked. I show two methods, one for each sail. That for the aft sail is the easiest to understand.

On putting about, when the sails lose their drive, the forward downhaul and sheet are eased off and the aft one is given a sharp pull, thus shooting the sail forward. I think this may cause the sail to flop around onto the new tack. The downhauls are then correctly adjusted, the sheet is pulled in and the sail is ready for working. The system drawn for the fore sail uses the downhauls as sheets, too. The forward one is hauled tight in when sailing close-hauled. The aft one doubles as a sheet. On putting about, the fore downhaul/sheet is slacked off and the sail falls forward. It may do so enough to make it flop onto the new tack but if it does not, the aft sheet/downhaul can be pulled forward to drive it around, as with the method used for the aft sail.

THE SECTIONS

These are those of the skipjack Messenger. There may be some trouble getting plywood to twist onto the vertical stem and so I have put a little round there. The highly cambered deck should avoid windage from a coach roof and be easier to build. The leeside of the deck would be hard to get about on when the boat is heeled.

Details of the centreboard and its trunk and plugs are shown with the position of the 'outboard motor.'

ACCOMODATION.

The deck plan shows the 5 foot wide cockpit with side benches. It also again shows the sheeting arrangements. Three motor car-type seats with folding backs are used forward.

This boat is designed for permanent living accommodation for my wife and self with, as occasional visitors, our three daughters and husbands and five grand-children.

The owner's cabin is aft with its own shower, basin, heads and locker space. Forward of this is the galley and chart table which can also be used as an extra berth if needed. The dining table can also convert to a double berth. Unfortunately, one side must fold to let people get into the forward side because of the centreboard box.

All the forward accommodation is given over to berths, two 6 foot ones, two 6 ft. 6 ins. ones, while a separate cabin has a double berth. This cabin would be my office when not used for visitors. Forward of all this is a shower, basin and heads for visitors. Two or even three people can be slept in the cockpit benches and seats. Thus, 13–14 people could be accomodated as a temporary measure.

When not crammed with people in every conceivable place, however, this yacht would make a pleasant permanent home for my wife and myself which should be easy to run.

CONCLUSION

A review of some sailing facts and figures leads us to the actual figures of performance of some sailing yachts. Dick Newick's Val trimaran appears to be the fastest possible sailing craft for her sail area, even though C and D Class catamarans may well be faster. It is noted that the length to beam ratio of Val's hull is 11.0 and so her L.D.R. will also approximate to 11.0.

We then proceed to use these figures for speed in the design of a 'Sailing Houseboat,' Sawsbrulder. The result looks fairly good as a houseboat. It would indeed be interesting to see how she would perform as a sailing boat.

Fig. 1

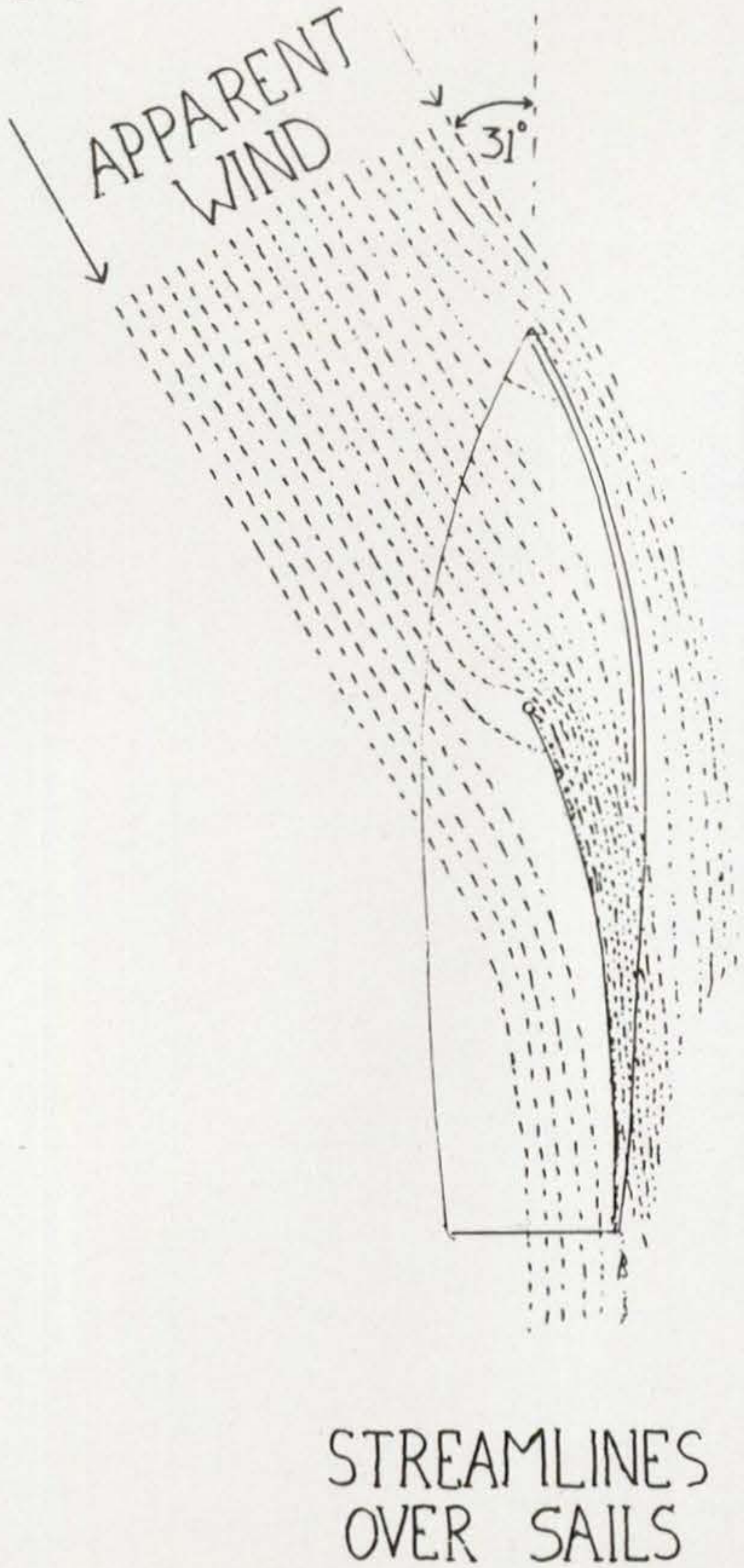

APPARENT
WIND
31°
STREAMLINES
OVER SAILS

Fig. 2

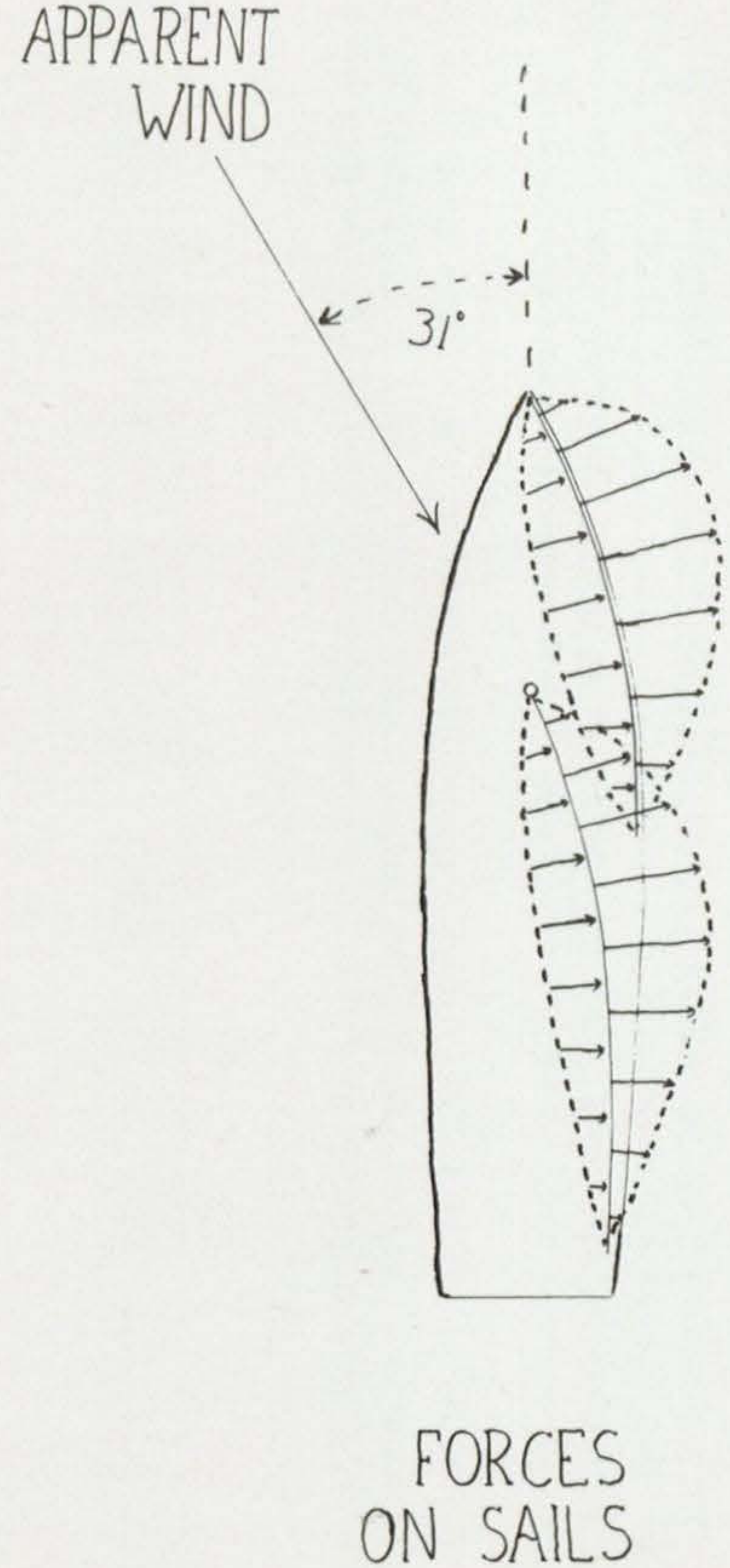
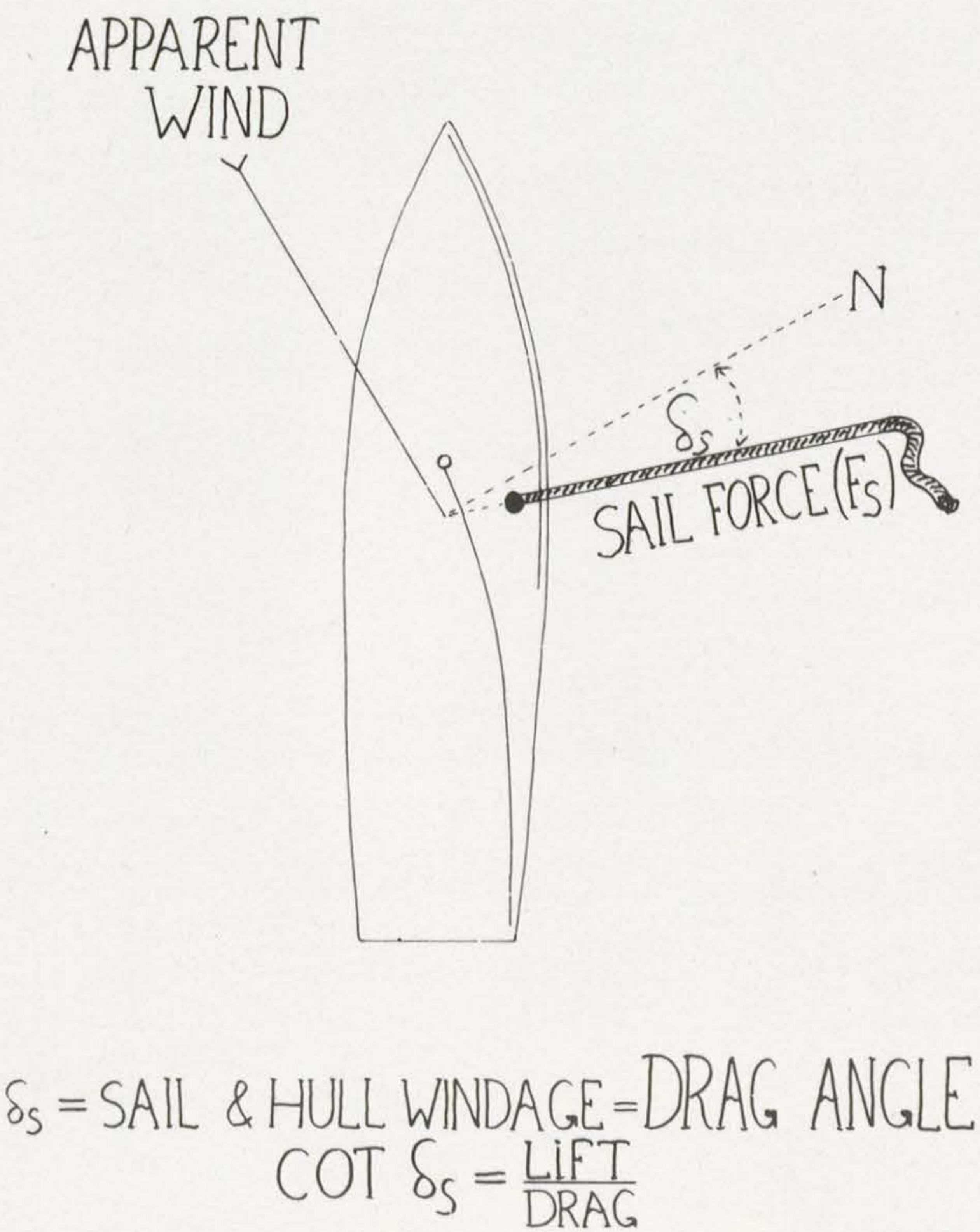
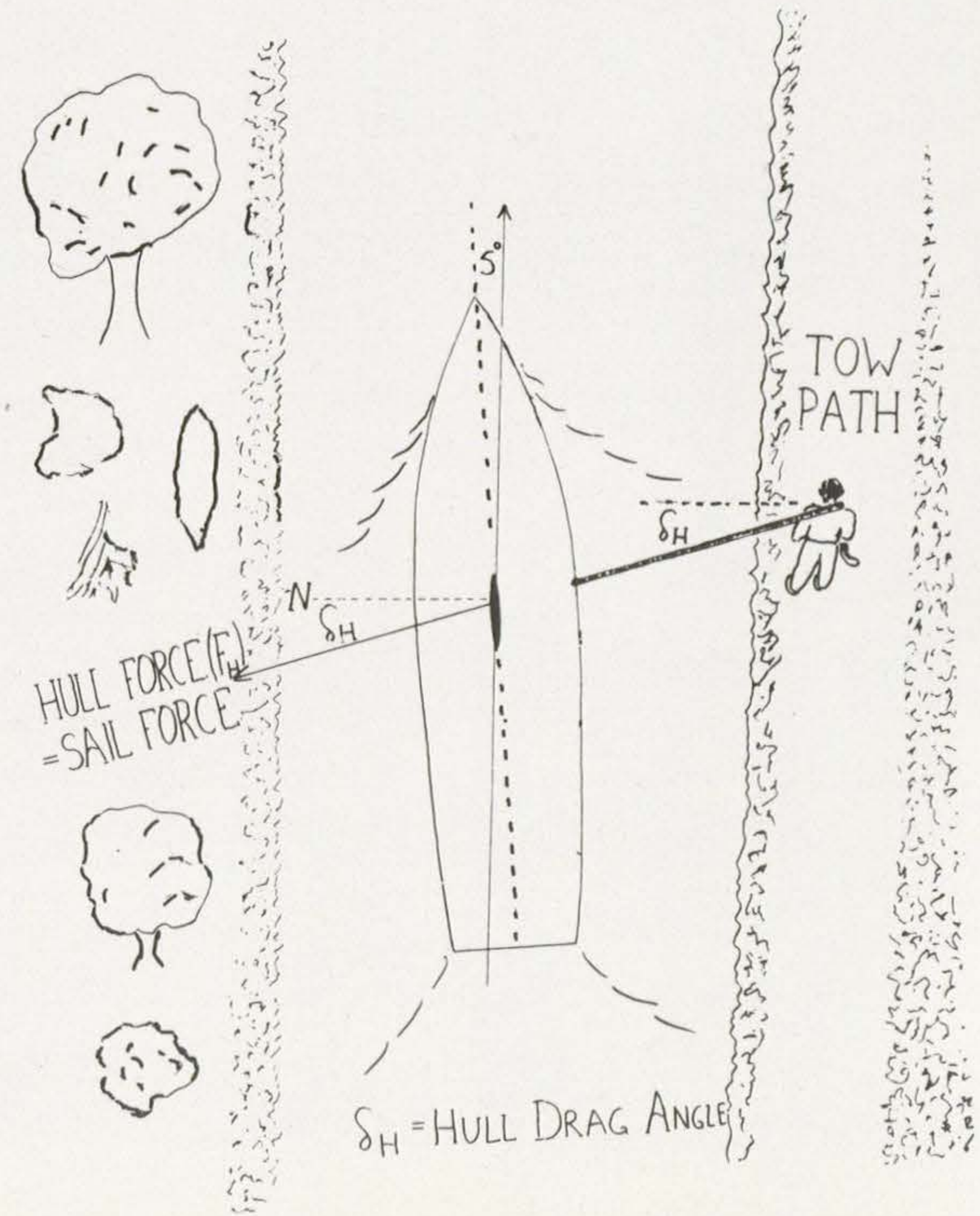

APPARENT
WIND
31°
FORCES
ON SAILS

Fig. 3



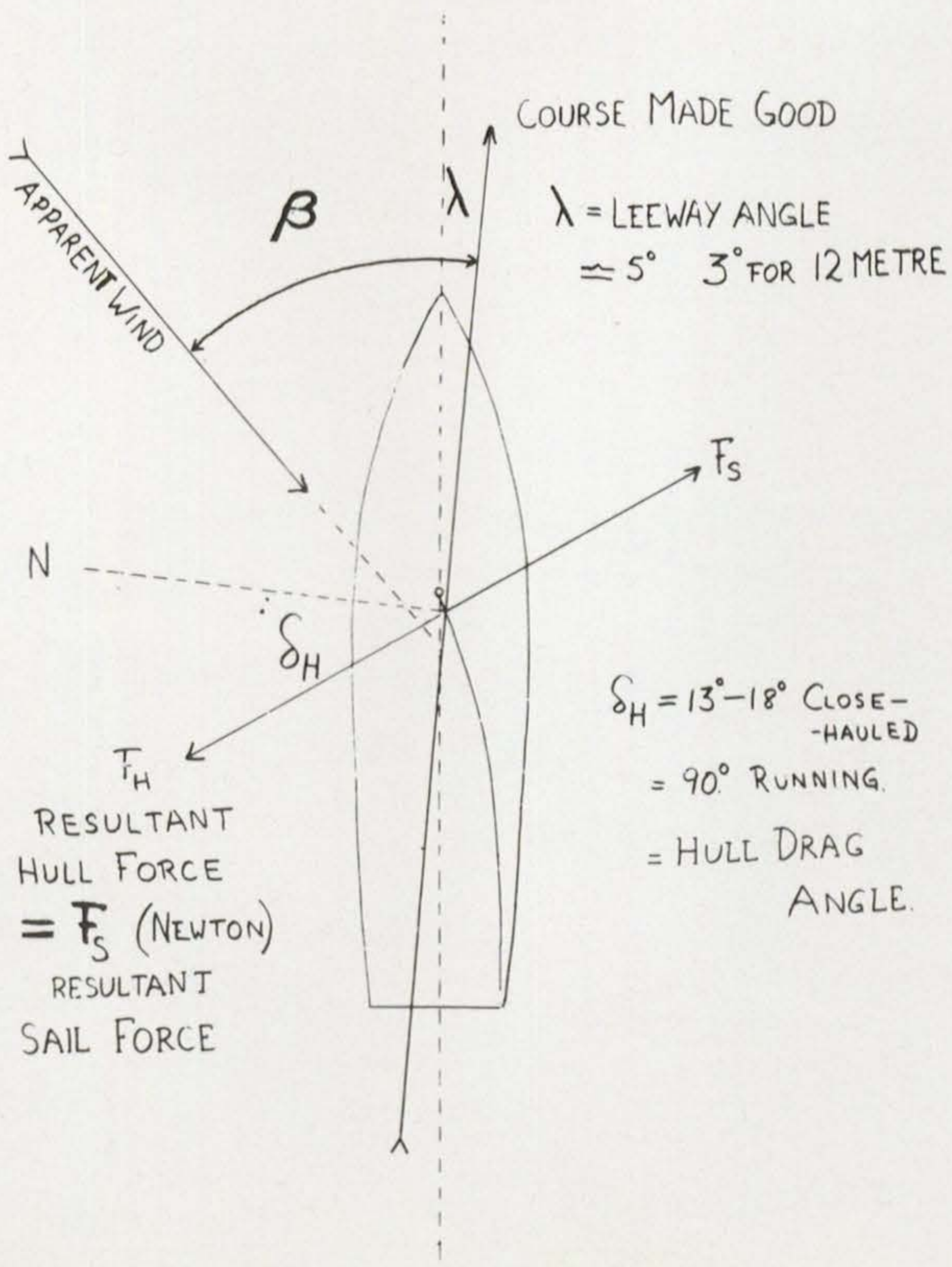
APPARENT WIND
N
δ_S
SAIL FORCE (F_S)
δ_S = SAIL & HULL WINDAGE = DRAG ANGLE
COT $\delta_S = \frac{\text{LIFT}}{\text{DRAG}}$

Fig. 4



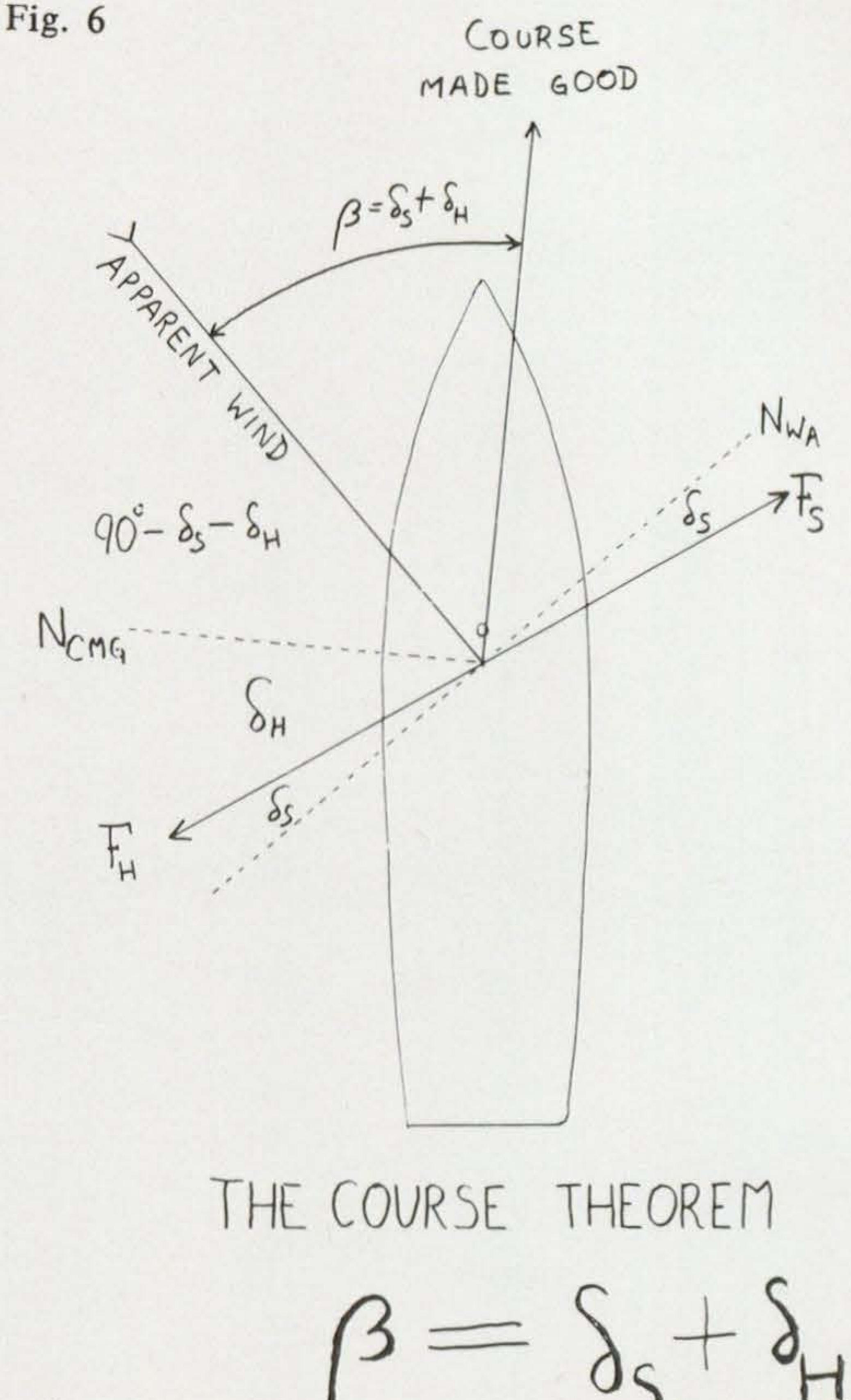
5°
TOW PATH
δ_H
N
δ_H
HULL FORCE (F_H) = SAIL FORCE
δ_H = HULL DRAG ANGLE

Fig. 5



COURSE MADE GOOD
APPARENT WIND
β
λ
λ = LEEWAY ANGLE
≃ 5° 3° FOR 12 METRE
F_S
N
δ_H
δ_H = 13°–18° CLOSE-HAULED
= 90° RUNNING
= HULL DRAG ANGLE
F_H
RESULTANT HULL FORCE
= F_S (NEWTON)
RESULTANT SAIL FORCE

Fig. 6



COURSE MADE GOOD
$\beta = \delta_S + \delta_H$
APPARENT WIND
N_{WA}
δ_S
F_S
$90° - \delta_S - \delta_H$
N_{CMG}
δ_H
δ_S
F_H
THE COURSE THEOREM
$\beta = \delta_S + \delta_H$

Fig. 7

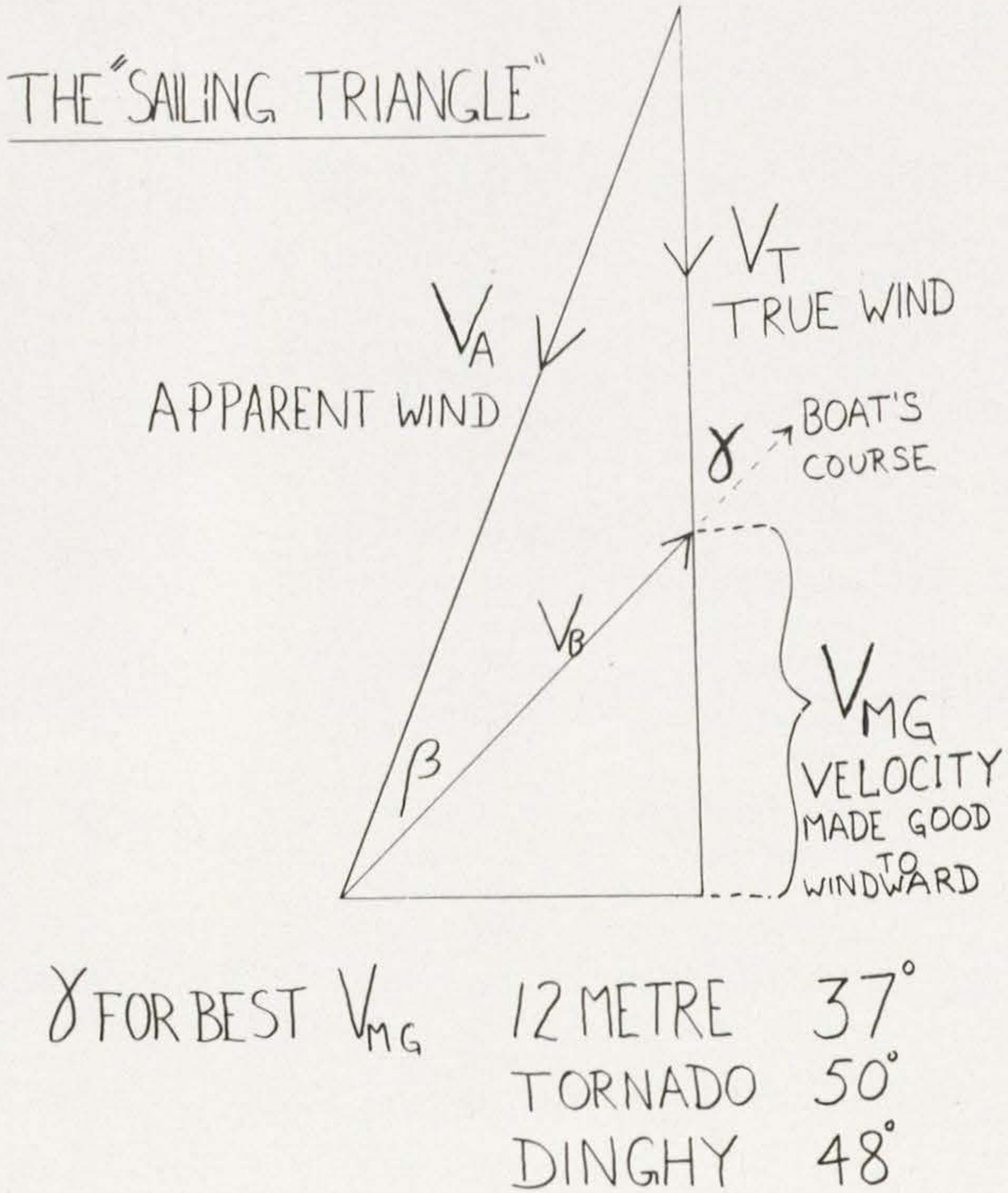

THE "SAILING TRIANGLE"
V_T
TRUE WIND
V_A
APPARENT WIND
γ
BOAT'S COURSE
V_B
β
V_{MG}
VELOCITY MADE GOOD TO WINDWARD
γ FOR BEST V_{MG}
12 METRE 37°
TORNADO 50°
DINGHY 48°

Fig. 8.

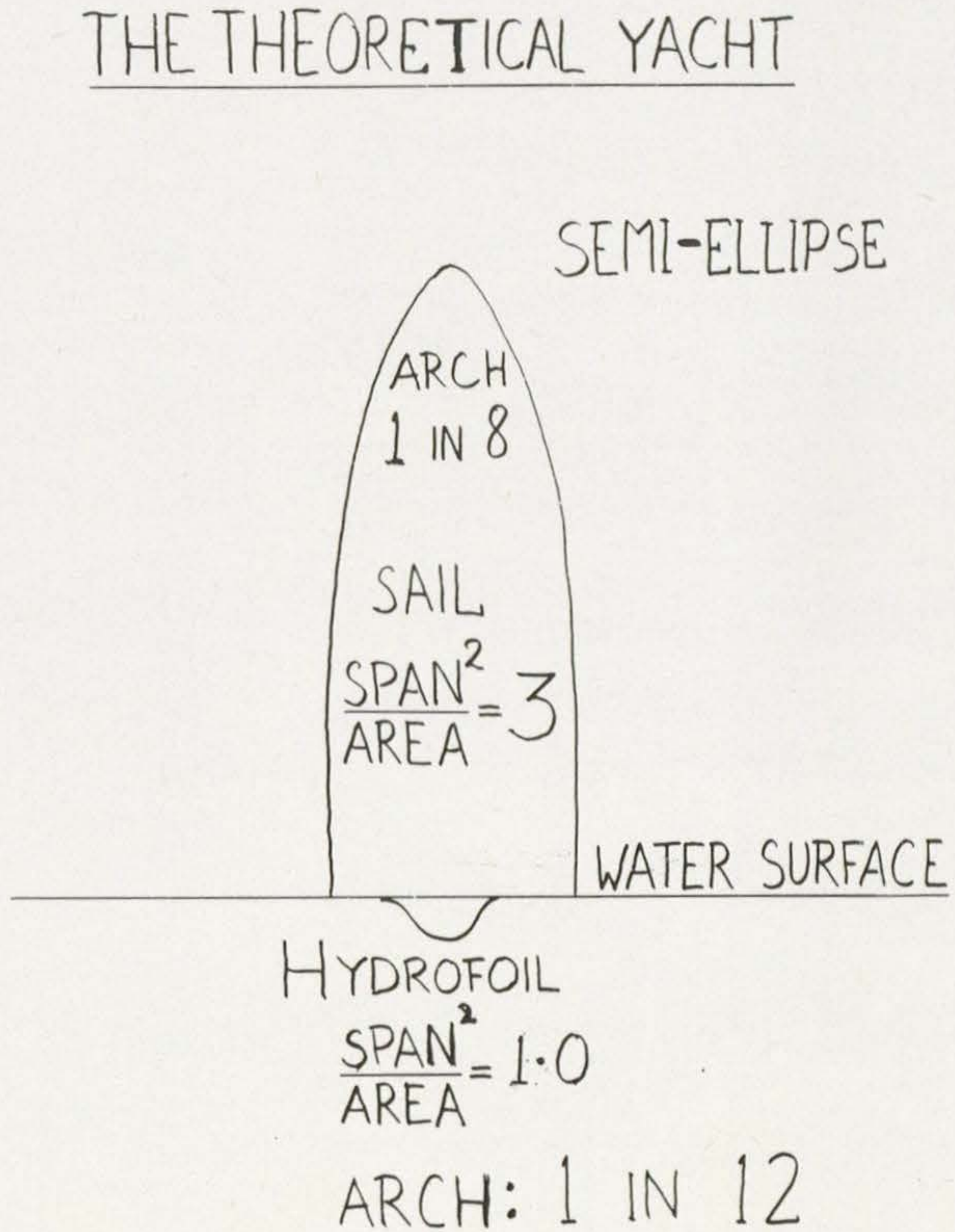
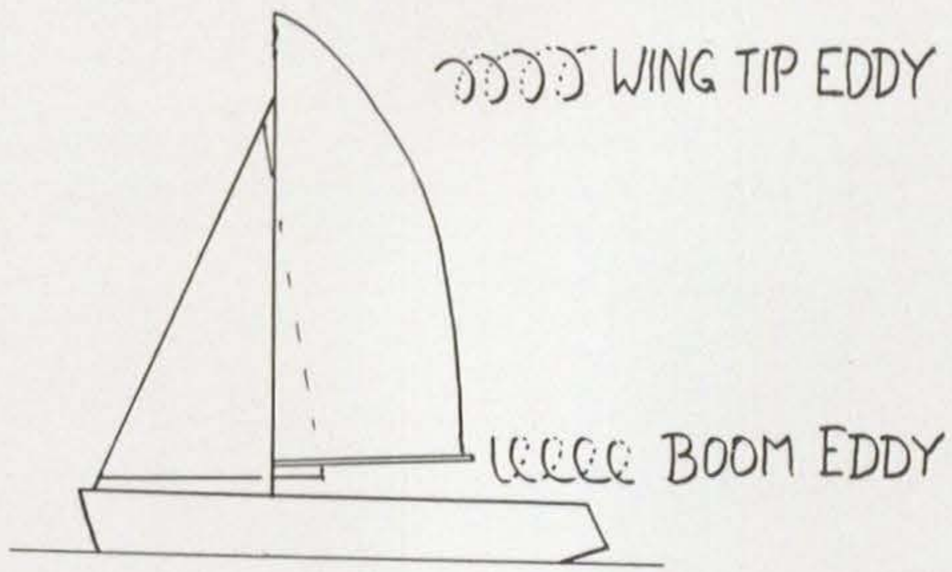

THE THEORETICAL YACHT
SEMI-ELLIPSE
ARCH 1 IN 8
SAIL
$\frac{\text{SPAN}^2}{\text{AREA}} = 3$
WATER SURFACE
HYDROFOIL
$\frac{\text{SPAN}^2}{\text{AREA}} = 1{\cdot}0$
ARCH: 1 IN 12

Fig. 9.

SAIL LOSSES

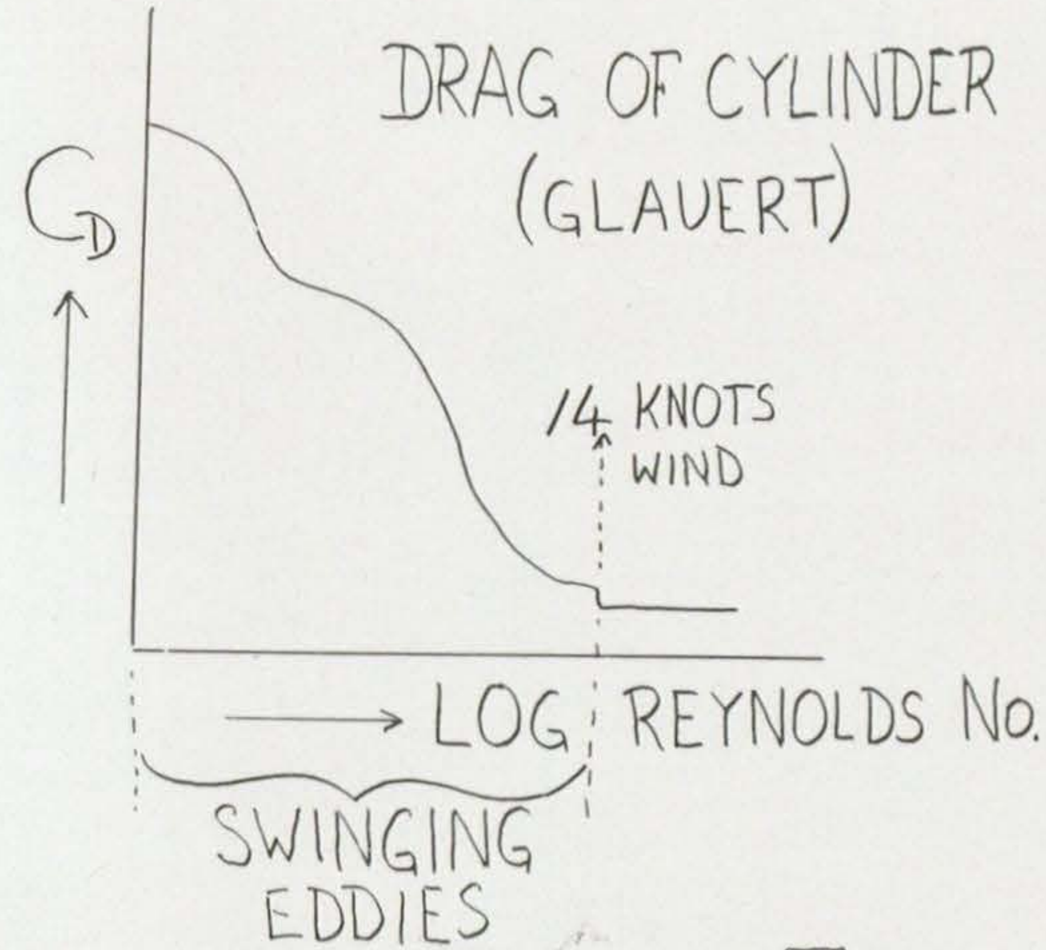


MAST AS "SPOILER" (JIB RETRIEVES SOME)	18%
LOSS AT PEAK	10%
TWIST OF SAIL	20%
FALLING IN AT LUFF	10%
BOOM EDDY	20%
STRAIGHT JIB LUFF (SHOULD BE CONVEX)	10%

C_S MOSTLY 1·2 = FLAT PLATE

Fig. 10.

AERODYNAMICS < 14 KNOT WIND



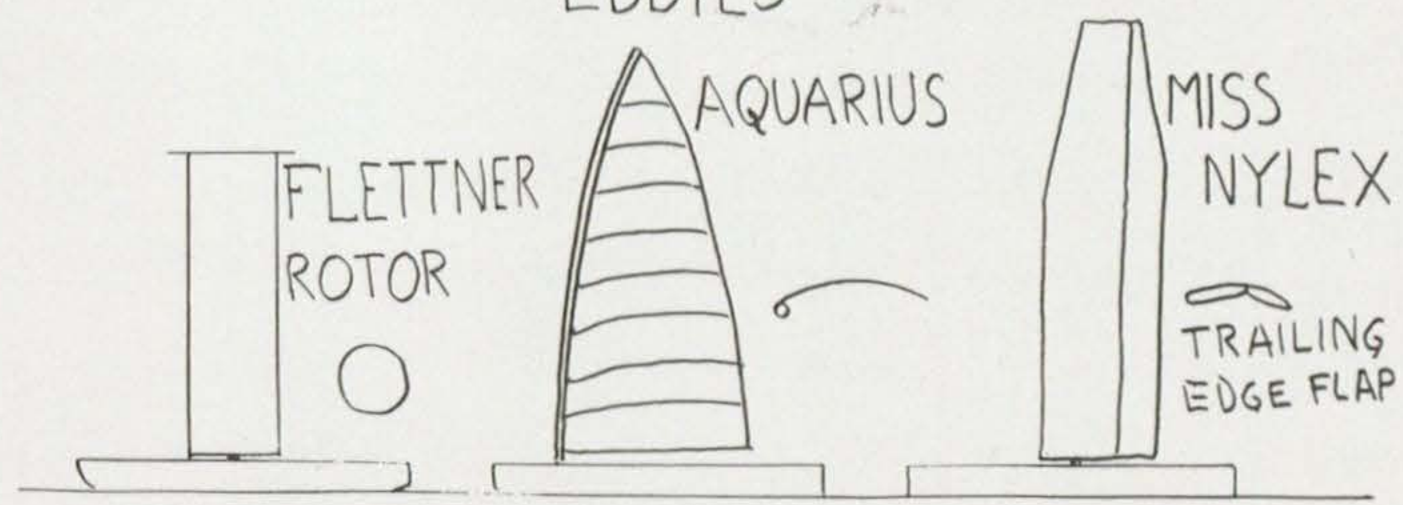


Fig. 11

HYDROFOILS

CENTREBOARDS & FIN KEELS

BEST $\frac{\text{SPAN}^2}{\text{AREA}} \simeq 1{\cdot}0$

$\therefore$ NOT A HYDROFOIL — FORCE DUE TO SURFACE EFFECT — WATER PUSHED TO LEE (+WAVE). HOLLOW TO WINDWARD.

? RELATE C.B. (FIN) PROFILE TO WAVE SHAPE ? VERSED-SINE & TROCHOID.

SQUARE METRE YACHTS. HIGH C.L.R.

Fig. 12

FIGURES

γ COURSE $(+\lambda)$ TO TRUE WIND.

β " $(+\lambda)$ " APPARENT " .

λ LEEWAY ANGLE.

δ_S SAIL (+WINDAGE) DRAG ANGLE.

δ_H HULL (+PROP. ETC.) " " .

V_T TRUE WINDSPEED.

V_A APPARENT " " .

V_B BOAT SPEED.

V_{MG} VELOCITY TO WINDWARD.

$C_S = F_S / \tfrac{1}{2}\rho A v^2$

$K_H = 100\, R_T / W^{2/3} V_B^2$, R_T & W-LBS, V_B-KTS

$B_R = A_S^{1/2} / W^{1/3}$. $\frac{V_B}{V_A} = \frac{\sqrt[2]{A_S}}{\sqrt[3]{W}} \sqrt{\frac{C_S}{K_H}} \times 0{\cdot}585$.

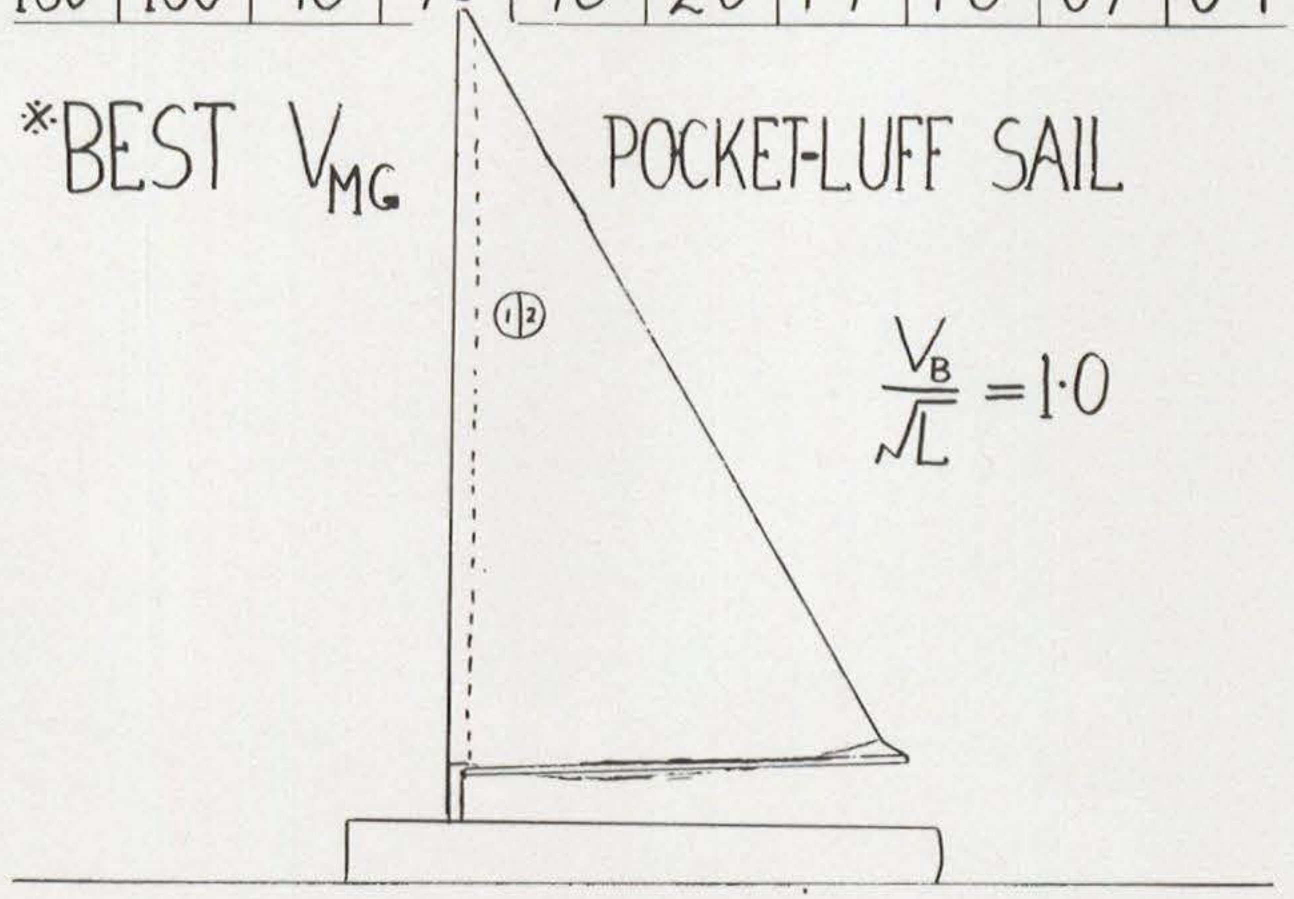
Fig. 13.

12 FT. INTERNATIONAL O.D.

γ	β	δ_S	δ_H	α	C_S	K_H	C_S/K_H	V_B/V_A	V_B/V_T
48°*	36°	18°	18°	26°	1·5	8·0	0·2	0·3	0·35
90°	60°	21°	39°	29°	1·6	3·2	0·5	0·5	0·55
180°	180°	90°	90°	90°	2·0	1·9	1·0	0·7	0·4

*BEST V_{MG}

POCKET-LUFF SAIL



$$\frac{V_B}{\sqrt{L}} = 1{\cdot}0$$

Fig. 14.

12 METRE. NET SAIL: $1{,}750^{\phi}$ Δ: 61,000 LBS.

WIND	γ	β	δ_S	δ_H	V_{MG}	V_B	C_S	K_H	B_R
10 KT	37°	22°	9°	13°	5·6	7·0	1·2	2·5	1·1
20 KT	38°	27°	11°	16°	6·5	8·4	0·9	3·6	1·1
10 KT	135°	86°	20°	66°		7·6	1·5	0·65	1·2
20 KT	150°	106°				10	1·25	1·3	1·2
10 KT	180°	180°				5·7	1·8	0·5	1·2
20 KT	180°	180°				9·6	1·8	1·05	1·2

5·5 METRE "ANTIOPE" TESTED FULL SIZE

V_B KTS	$V_B/\sqrt{L}$	K_H 180°	K_H 39°	δ_H 39°	CLOSE-HAULED
3	0·6	0·5	2·0	18°	λ=1·6° δ_H=18°
4	0·8	0·55	2·0	18°	BAD. CANNOT
5	1·0	0·6	2·1	18°	CARRY S.A. FOR
6	1·2	0·8	2·4	20°	λ=5° δ_H=10°

Fig. 15

"VAL" TRIMARAN

L.O.A.: 31 ft. L.W.L.: 28 ft. BEAM: 25 ft.
SAILS: 450 SQ. ft. DISPL.: 2,830 LBS.
BR: 1·5. THIRD IN OSTAR, 17 HRS AFTER PEN DUICK (70 ft) IN 1976

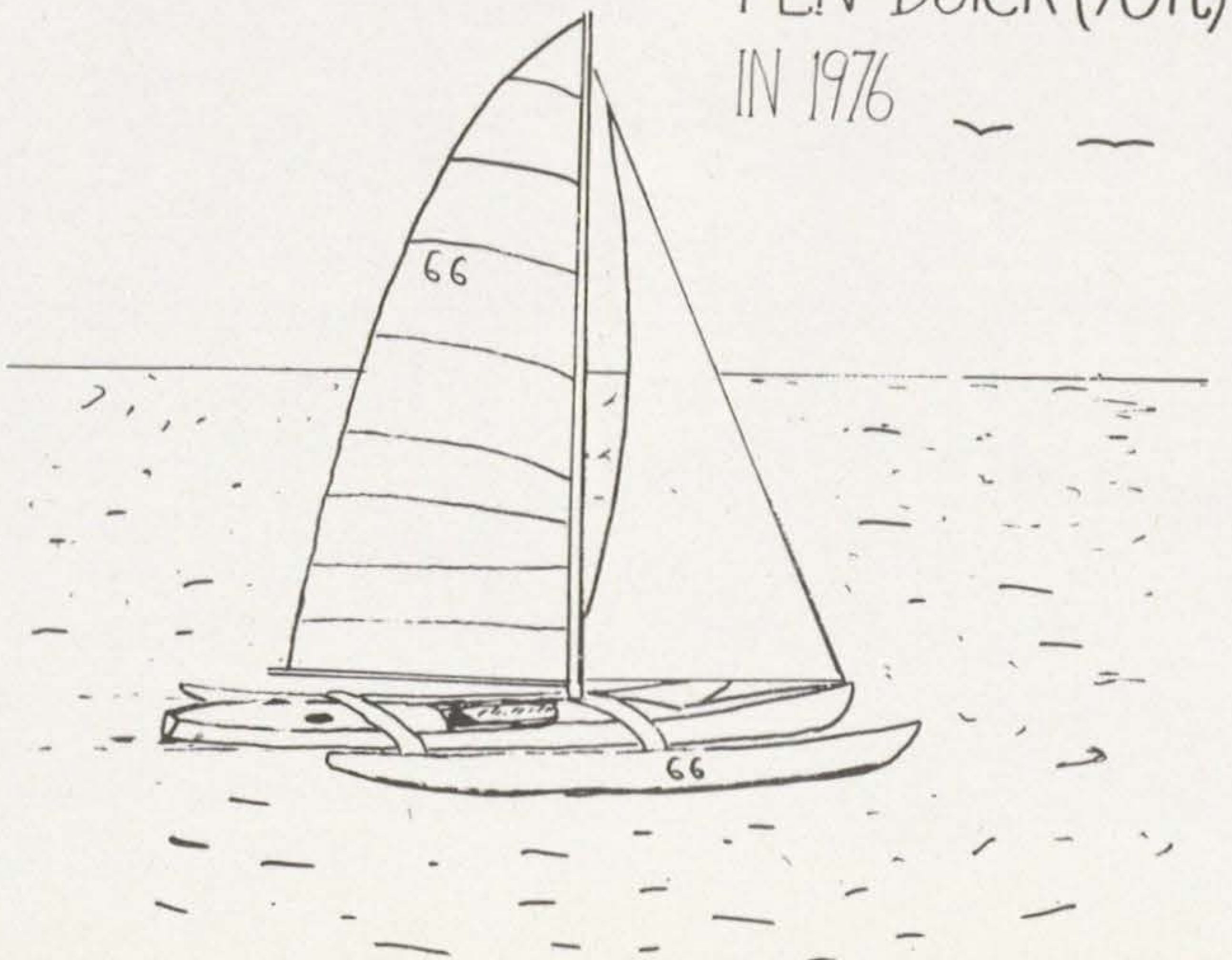


Fig. 16

"VAL" TRIMARAN (NEWICK) "GALLIARD"

MEASURED, HARRY MORSS 9.9.76.
6 BALLAST LANE, MARBLEHEAD MASS 01945, USA

							ASSUME			CALCULATE	
	γ	V_B/V_T	V_{MG}/V_T	β	λ	V_B/V_A	δ_H	δ_S	C_S	K	K_{HF}
PINCHED	27°	·33	·29	19°	5°	·26	10°	9°	·75	·624	1·48
	31°	·485	·42	21°	4°	·33	11°	10°	1·0	·755	1·35
	35°	·595	·49	22°	3°	·385	12°+	10°	1·15	·84	1·25
BEST V_{MG}	39°	·677	·53	23°	2½°	·43	13°	10½°	1·25	·91	1·17
	43°	·737	·54	25°		·46	14°	11°	1·3	·93	1·14
	45°	·76	·54	25½°	2°	·47	14½°	11°	1·3	·95	1·11
	49°	·806	·53	27°		·49	15½°	11½°	1·3	·95	1·11
	51°	·818	·51	27½°	1½°	·50	15½°	12°	1·3	·97	1·07

$$V_B/V_A = K\sqrt{\sin \delta_H} \;\therefore\; K = \frac{V_B/V_A}{\sqrt{\sin \delta_H}} = 0{\cdot}585\, B_R \sqrt{\frac{C_S}{K_{HF}}}$$

$$\therefore K_{HF} = \frac{0{\cdot}77\, C_S}{K^2} \quad (\text{VAL'S } B_R = 1{\cdot}5)$$

Fig. 17

ICE YACHTS

TOP SPEED 120 KTS. $V_B/V_T = 7{\cdot}0$

MAST: TURNING PLANK, CONCAVE

TO WINDWARD = TWIST-FREE SAIL,

FULLY BATTENED, ¼ ELLIPSE SAIL.

$\beta = 8{\cdot}2^\circ$. δ_H(MEASURED)$=1^\circ$ $\delta_S = 7{\cdot}2^\circ$

Fig. 18

DESIGNING

SAWSBRULDER

$S.A./W.S. \triangleq 3{\cdot}0$

$Br.\ No. \triangleq 1{\cdot}5$

$L.D.R. \triangleq 11{\cdot}0$

Fig. 19.

S.A./W.S. RATIO

$F_S \propto A_S V_A^2$.

BELOW $V_B/\sqrt{L}$ OF 0·7,

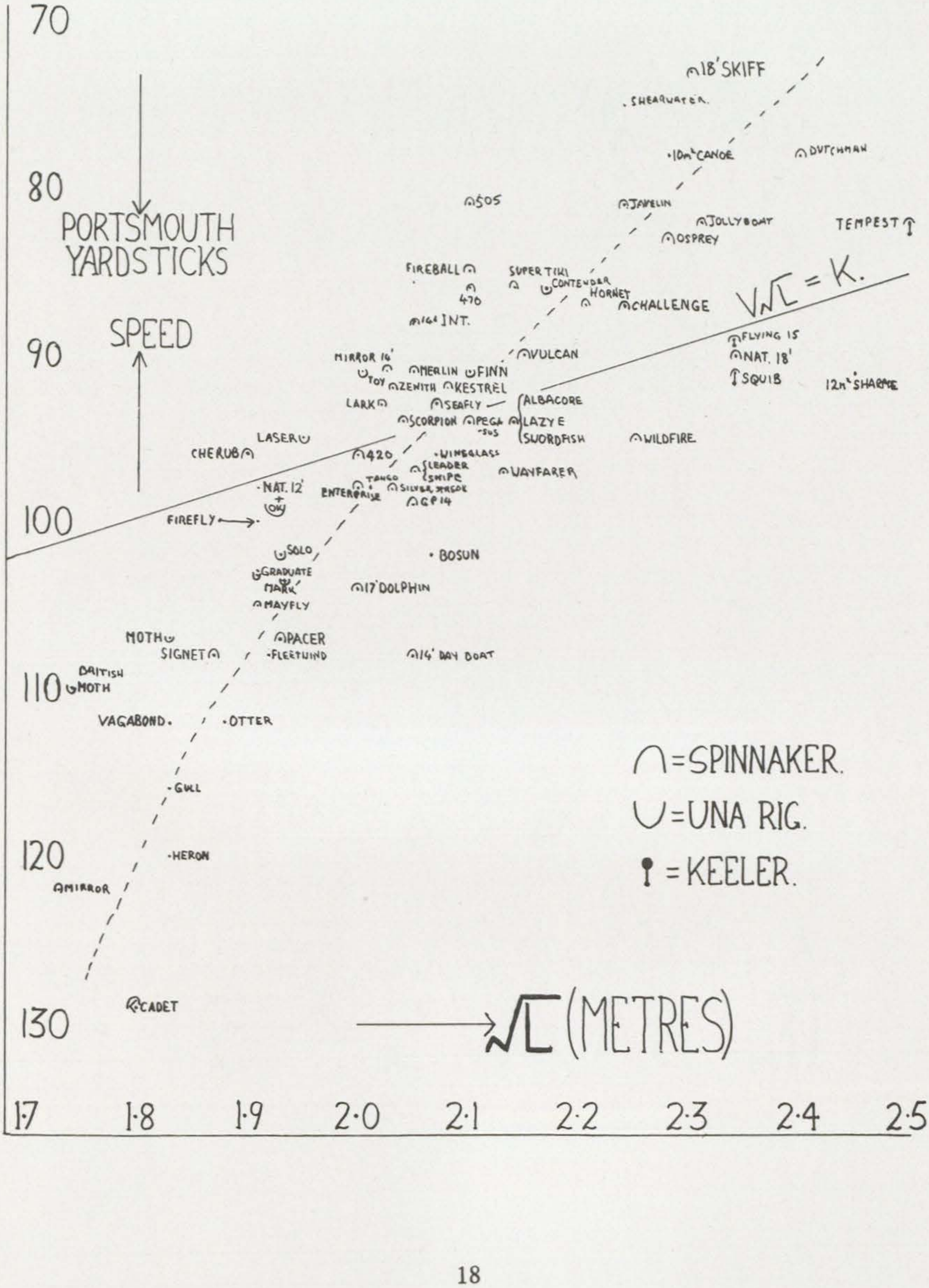
$F_H \propto V_B^2$ (SKIN FRICTION $\propto$ W.S.)

$F_S = F_H$. $\therefore V_B \propto V_A \propto \sqrt{A_S}$

A BOAT IS A GOOD "DRIFTER"

IF S.A./W.S. $\triangleq$ 3

Fig. 20.



PORTSMOUTH YARDSTICKS
SPEED
√L (METRES)
√L = K.
∩ = SPINNAKER.
∪ = UNA RIG.
= KEELER.
70
80
90
100
110
120
130
1·7
1·8
1·9
2·0
2·1
2·2
2·3
2·4
2·5
18' SKIFF
SHEARWATER
10m² CANOE
DUTCHMAN
505
JAVELIN
JOLLYBOAT
OSPREY
TEMPEST
FIREBALL
SUPER TIKI
CONTENDER
HORNET
CHALLENGE
470
16' INT.
FLYING 15
NAT. 18'
SQUIB
VULCAN
MIRROR 16'
TOY
MERLIN
FINN
ZENITH
KESTREL
LARK
SEAFLY
ALBACORE
LAZY E
SWORDFISH
SCORPION
PEGASUS
WILDFIRE
LASER
CHERUB
420
WINEGLASS
LEADER
SNIPE
WAYFARER
NAT. 12'
OK
TANGO
ENTERPRISE
SILVER JUBILEE
GP 14
FIREFLY
SOLO
BOSUN
GRADUATE
MAYFLY
17' DOLPHIN
MOTH
SIGNET
PACER
FLEETWIND
14' DAY BOAT
BRITISH MOTH
VAGABOND
OTTER
GULL
HERON
MIRROR
CADET

Fig. 21.

RACING SPEED & $\sqrt{L}$ GRAPH

1. LONGER BOATS ARE FASTER.
2. UNA RIG IS FASTER. AT MAX. V_{MG}, $C_S = 1{\cdot}5$ — SLOOP'S $= 1{\cdot}3$. BEST BOATS: 8 UNAS, FROM 34
3. SPINNAKERS DON'T ADD VISIBLY TO SPEED.
4. TRAPEZE OR SLIDING SEAT-VERY USEFUL.
5. HARD CHINE AS FAST AS ROUND BILGE.
6. V_B <u>NOT</u> $\propto \sqrt{L}$ (HEAVY LINE). MEAN-DASHED. REASONS: a) WAVES SLOW SMALL BOATS. b) LOW L.D.R.|HIGH D.L.R. c) WIND SCALING

Fig. 22.

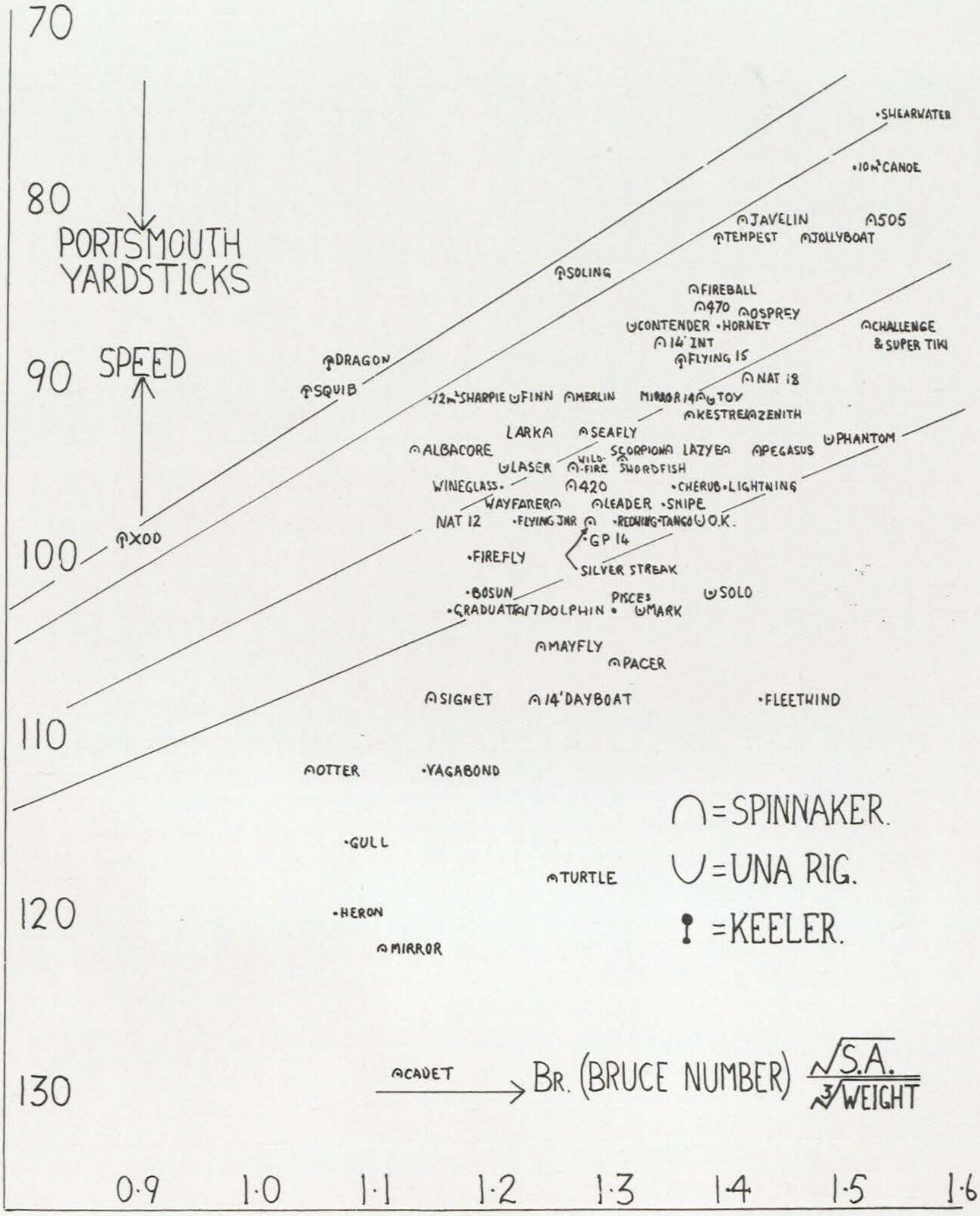

PORTSMOUTH YARDSTICKS
SPEED
Br. (BRUCE NUMBER) $\frac{\sqrt{S.A.}}{\sqrt[3]{WEIGHT}}$
= SPINNAKER.
= UNA RIG.
= KEELER.
SHEARWATER
10m² CANOE
JAVELIN
505
TEMPEST
JOLLYBOAT
SOLING
FIREBALL
470
OSPREY
CONTENDER
HORNET
CHALLENGE & SUPER TIKI
14' INT
FLYING 15
DRAGON
NAT 18
SQUIB
12m² SHARPIE
FINN
MERLIN
MIRROR 14
TOY
KESTREL
ZENITH
LARK
SEAFLY
ALBACORE
SCORPION
LAZYE
PEGASUS
PHANTOM
LASER
WILD-FIRE
SWORDFISH
WINEGLASS
420
CHERUB
LIGHTNING
WAYFARER
LEADER
SNIPE
NAT 12
FLYING JNR
REDWING
TANGO
O.K.
XOD
GP 14
FIREFLY
SILVER STREAK
BOSUN
PISCES
SOLO
GRADUATE
17 DOLPHIN
MARK
MAYFLY
PACER
SIGNET
14' DAYBOAT
FLEETWIND
OTTER
VAGABOND
GULL
TURTLE
HERON
MIRROR
CADET
70
80
90
100
110
120
130
0·9
1·0
1·1
1·2
1·3
1·4
1·5
1·6

Fig. 23.

RACING SPEED & BRUCE NUMBER

SPEED $\propto$ BR. No.

SMALL BOATS ARE SLOWED BY WAVES, L.D.R. & WIND SCALING.

UNA-RIGGED FINN & CONTENDER ARE TOP CLASS DINGHIES.

BALLASTED HULLS RATE WELL.

12 SQ.METRE SHARPIE IS THE BEST DINGHY, BUT IS HEAVY. THE "LIGHTWEIGHT SHARPIE" HAS A P.Y.No. 81.

Fig. 24.

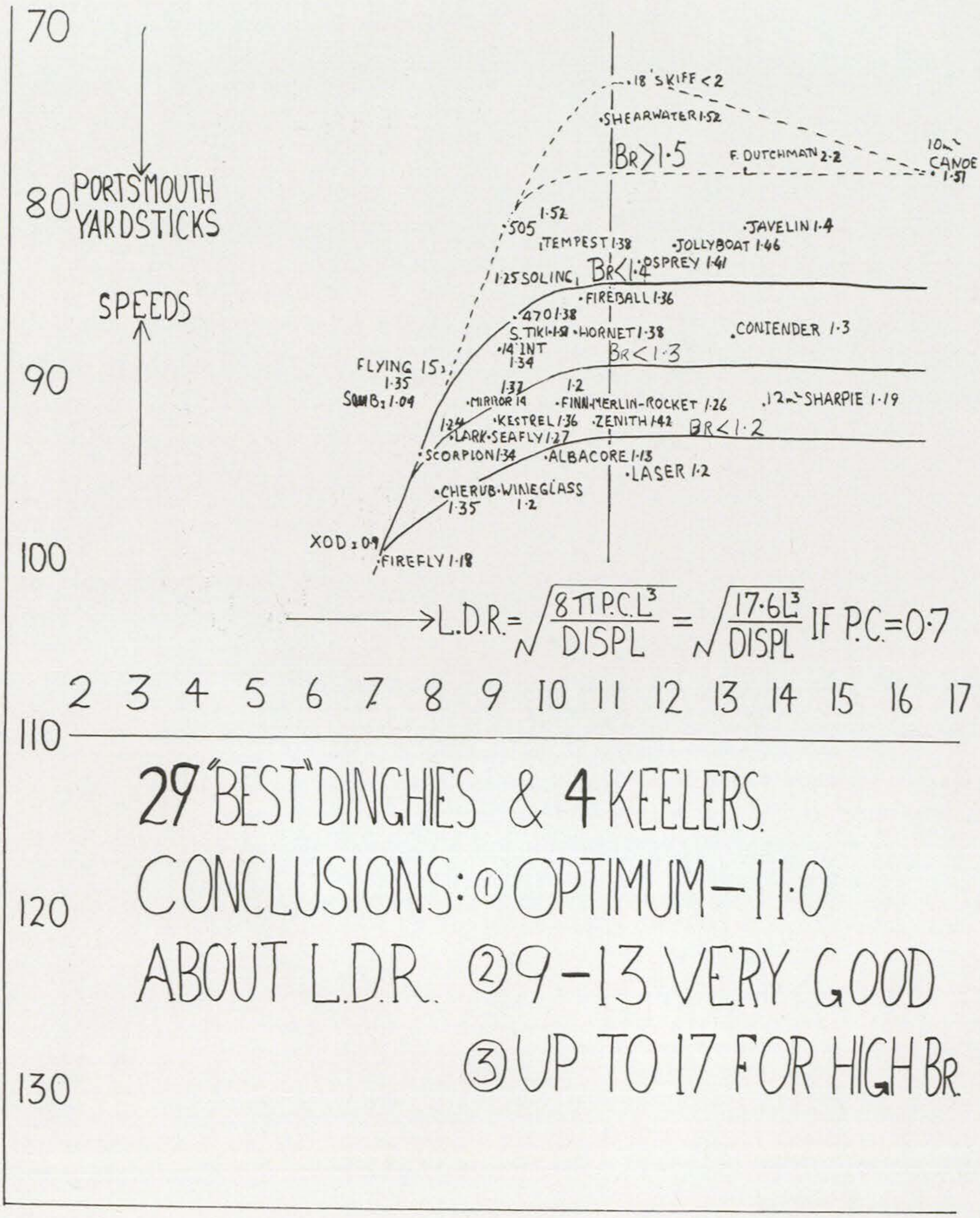

70
80
90
100
110
120
130
PORTSMOUTH YARDSTICKS
SPEEDS
18' SKIFF <2
SHEARWATER 1·52
Br>1·5
F. DUTCHMAN 2·2
10m² CANOE 1·51
505 1·52
TEMPEST 1·38
JOLLYBOAT 1·46
JAVELIN 1·4
1·25 SOLING
Br<1·4
OSPREY 1·41
FIREBALL 1·36
470 1·38
S. TIKI 1·52
HORNET 1·38
CONTENDER 1·3
14' INT 1·34
Br<1·3
FLYING 15 1·35
SQUIB 1·04
1·32 MIRROR 14
1·2 FINN MERLIN-ROCKET 1·26
12m² SHARPIE 1·19
1·24 KESTREL 1·36
ZENITH 1·42
Br<1·2
LARK SEAFLY 1·27
SCORPION 1·34
ALBACORE 1·13
LASER 1·2
CHERUB 1·35
WINEGLASS 1·2
XOD 0·9
FIREFLY 1·18
L.D.R. = √(8πP.C.L³ / DISPL) = √(17·6L³ / DISPL) IF P.C = 0·7
2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
29 "BEST" DINGHIES & 4 KEELERS
CONCLUSIONS: ① OPTIMUM – 11·0
ABOUT L.D.R. ② 9 – 13 VERY GOOD
③ UP TO 17 FOR HIGH Br

Fig. 25.

THE TEN BEST DINGHIES

	BR.	L.D.R.	BILGE	SPIN	TRAP.	RIG.
10 m² CANOE	1·50	16·50	CHINE	NO	YES	SLP.
505	1·52	9·15	ROUND	YES	YES	SLP.
JAVELIN	1·40	13·8	CH.?	YES	YES	SLP.
FIREBALL	1·36	10·5	CH.	YES	YES	SLP.
470	1·38	9·35	RD.	YES	YES	SLP.
CONTENDER	1·31	12·8	CH.	NO	NO	UNA
14 Ft. INT.	1·34	9·1	RD.	YES	YES	SLP
FINN	1·21	10·11	RD.	NO	NO	UNA
LARK	1·24	8·4	RD?	YES	?	SLP
LASER	1·20	11·3	RD.	NO	NO	UNA

Fig. 26.

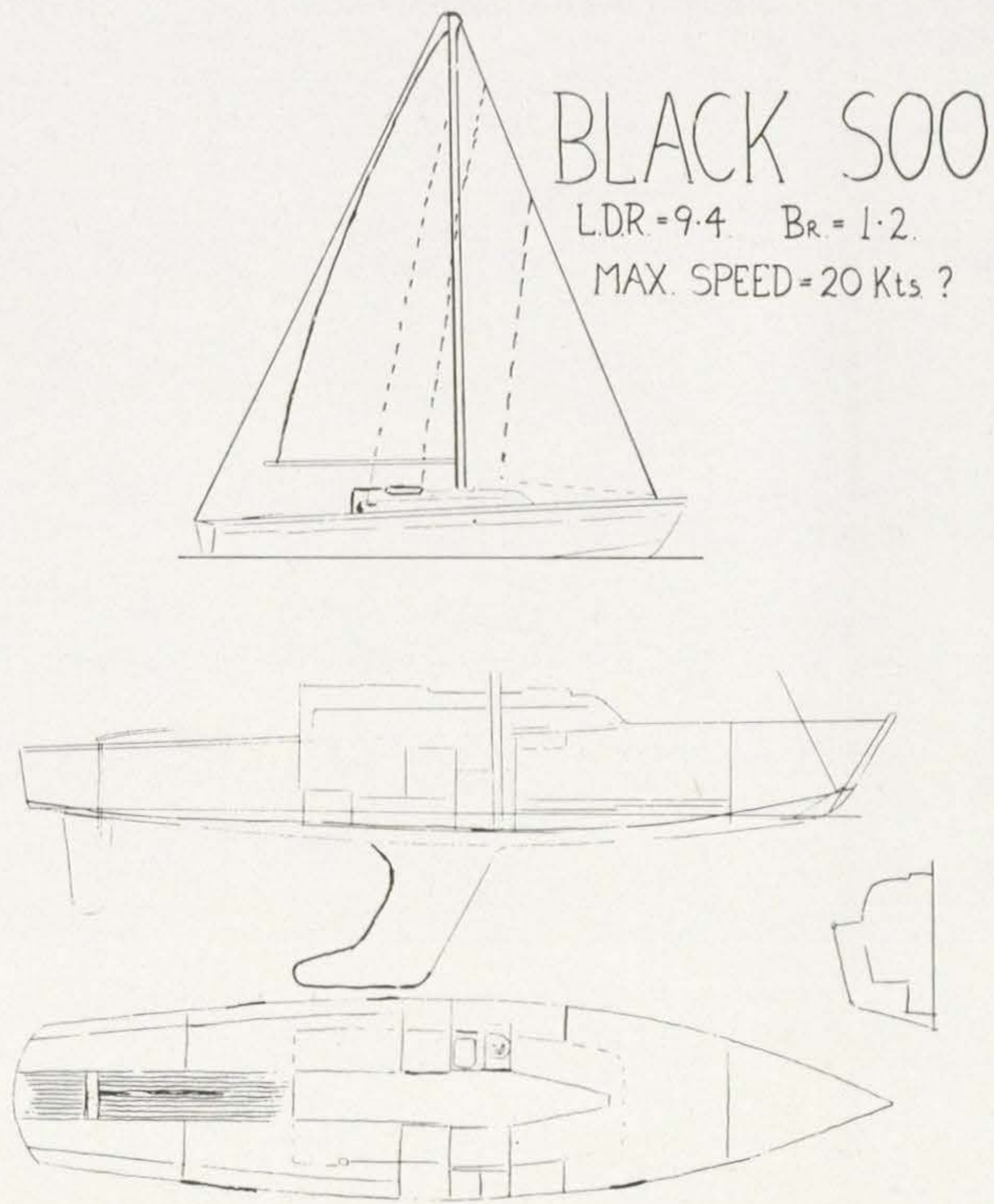
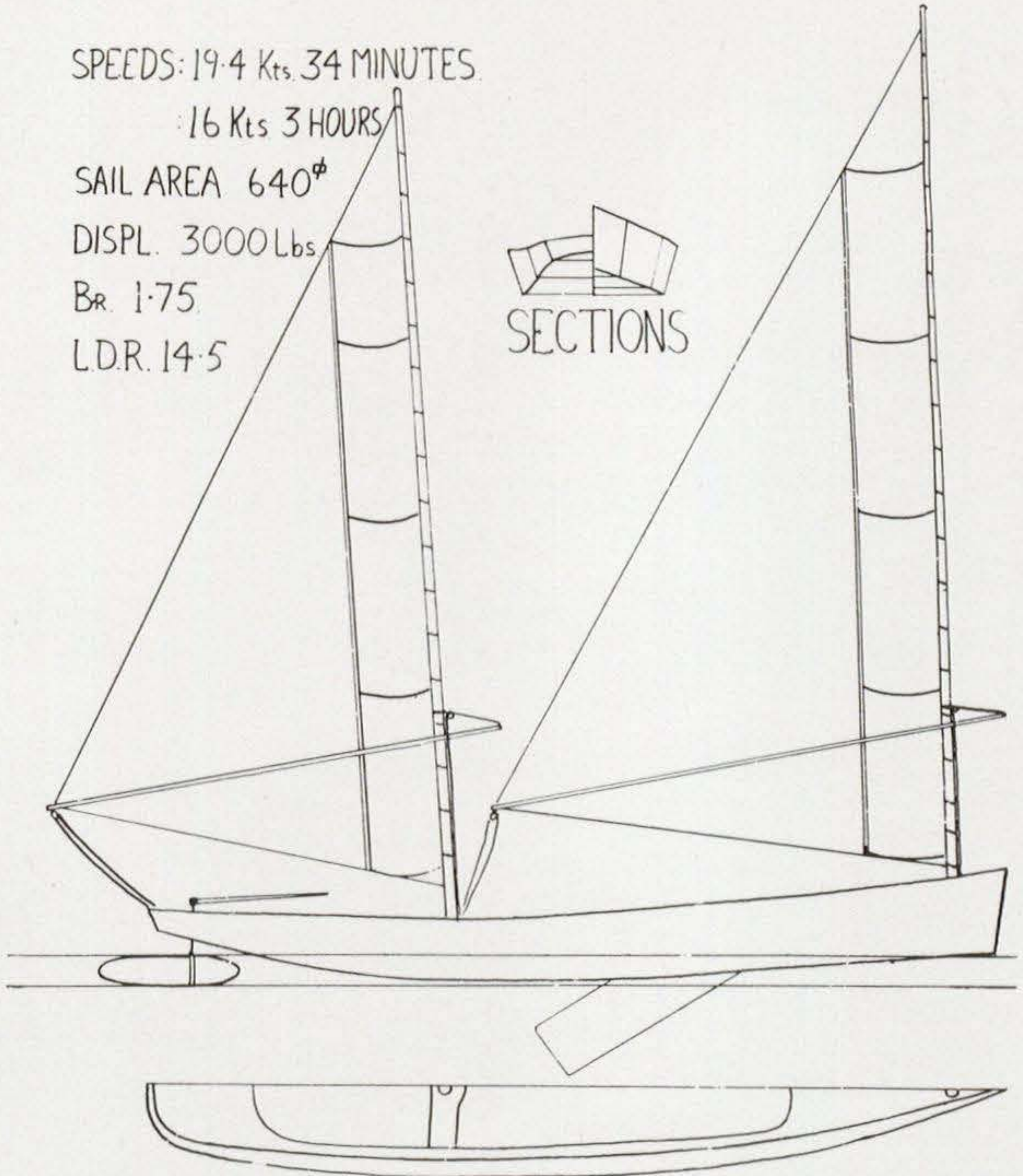
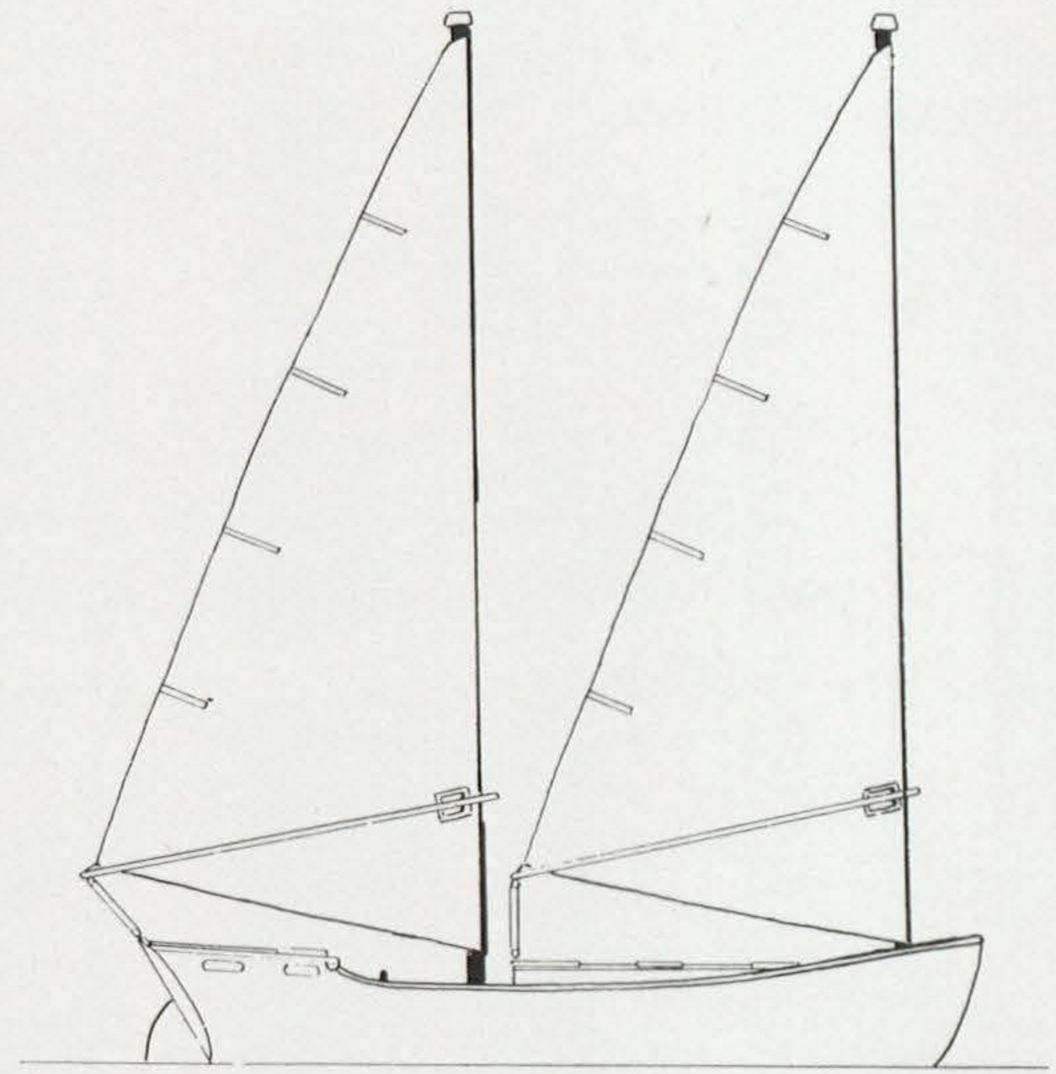


Fig. 27.



1870-1890 NEW HAVEN 35' SHARPIE

Fig. 28.

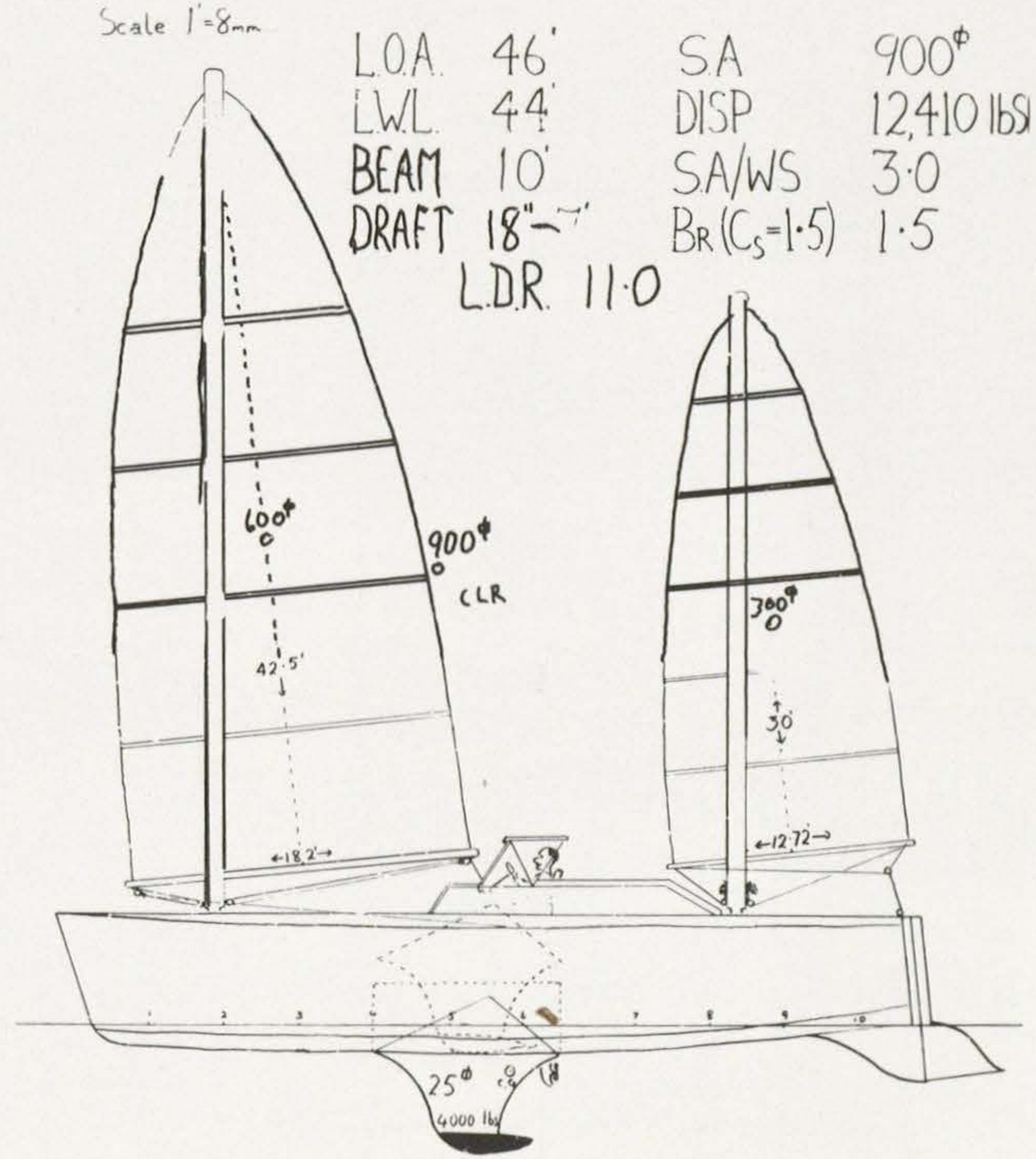


LOA 40 ft. FREEDOM 40 (1976) DRAFT 3'4"-6'6"
LWL 35 ft. S.A 784□
BEAM 12 ft. B_R=1·03. IF C_S=1·5, B_R=1·26 DISP 20,000

Fig. 29.

BATEAU OR SKIPJACK SMUGGLER
"MESSENGER"
Δ 12,200 Lbs. 35 Ft. X 10 Ft. Br 1·1.
SA 700$^{\phi}$ LDR 6·9

Fig. 30.



SAWSBRULDER

Fig. 31.

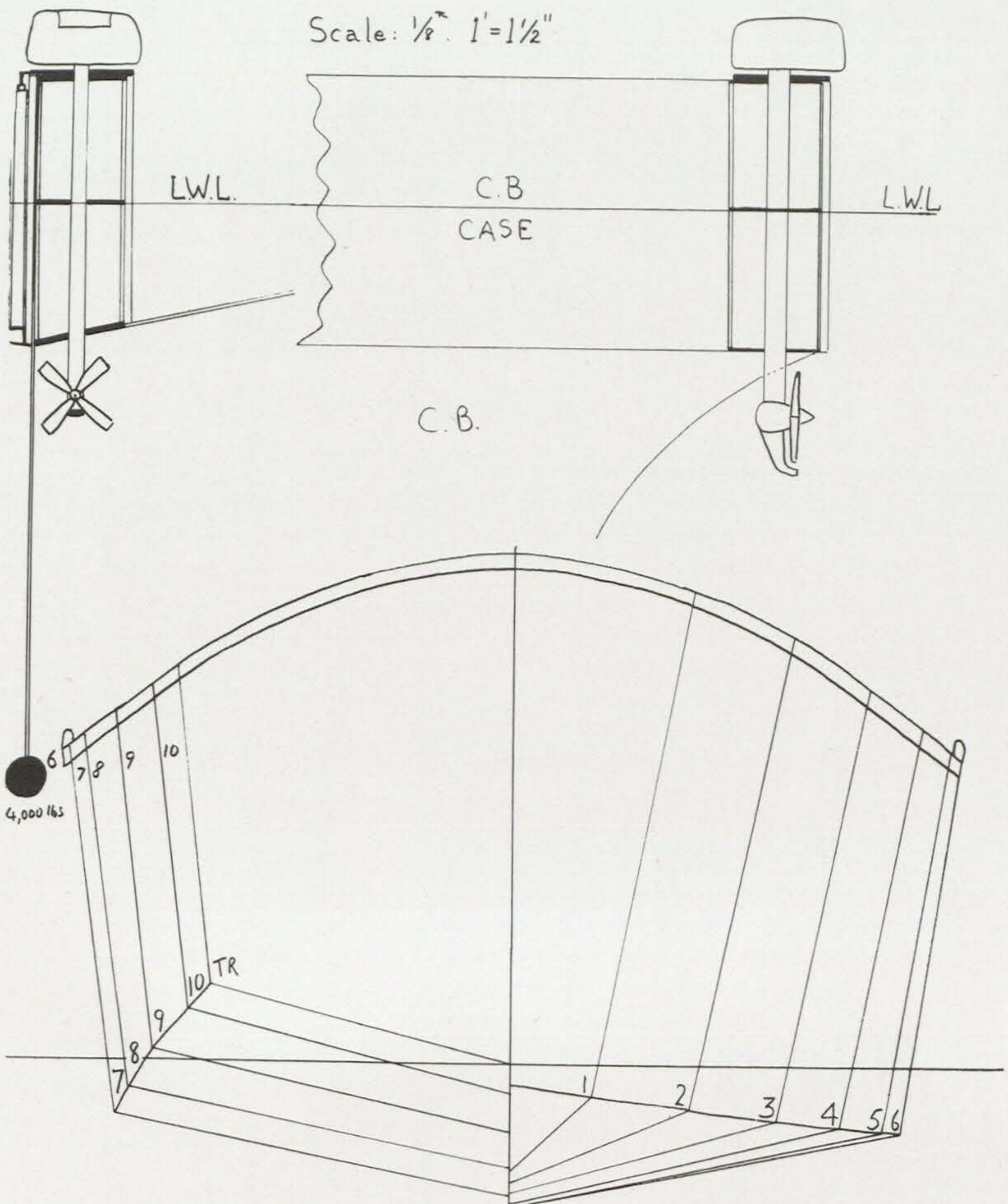
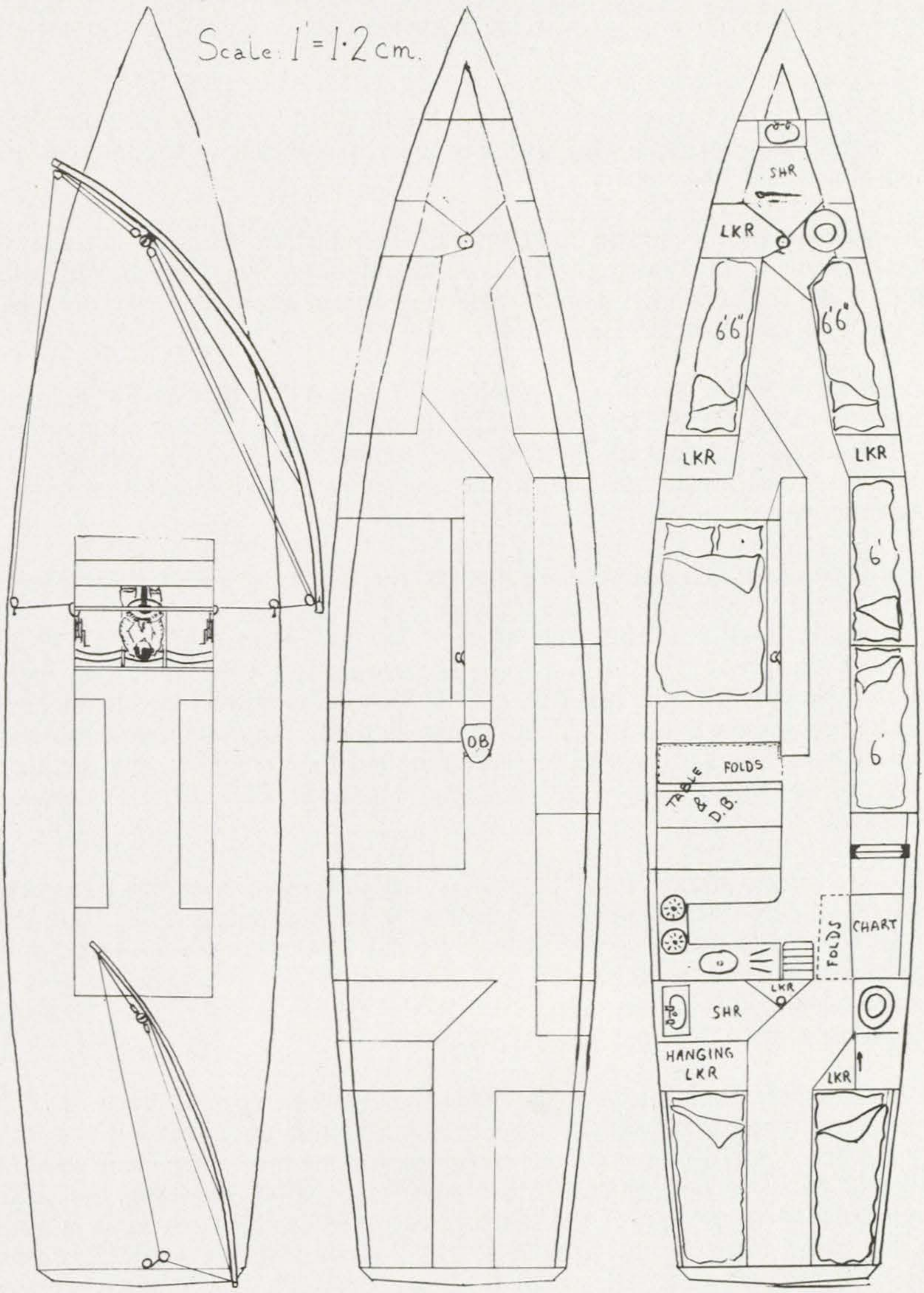

Scale: 1/8". 1'=1½"
L.W.L.
C.B
CASE
L.W.L
C.B.
4,000 lbs
6
7
8
9
10
10
TR
9
8
7
1
2
3
4
5
6

Fig. 32


Scale: 1' = 1·2 cm.
O.B.
SHR
LKR
6'6"
6'6"
LKR
LKR
6'
6'
FOLDS
TABLE & D.B.
FOLDS
CHART
LKR
SHR
HANGING LKR
LKR

THE DRAG ANGLES FOR BEST V_{MG}

by

John Morwood

The Course Theorem states:–"On any heading, the course made good from the apparent wind (the Beta angle) is equal to the sum of the sail and hull drag angles." $\beta = \delta_s + \delta_s$.

On learning of the course theorem, one's immediate reaction is to say:– "As a result of the course theorem, I think the best V_{MG} will be got when both drag angles are at their minimum." This statement is not so. There is a $3^o - 6^o$ difference.

In practical terms, the snag is 'pinching.' If a boat can be sailed at an angle from the wind LESS than that for the best V_{MG}, the course theorem will still hold and the sum of the drag angles must therefore be reduced. The best V_{MG} must occur when both drag angles are at least slightly more than their minimum.

I first checked Edmond Bruce's figures for the Twelve-foot International One-Design. The minimum drag angles were (given as L/D ratios):– Sail drag angle = 17^o 15′. Hull drag angle = 15^o 51′. These add up to 33^o 06′ whereas the beta angle for best V_{MG} is given as 36^o, with both drag angles at 18^o. Now, you might think that 2^o 56′ would be well within the range of experimental error–and would be if I were doing the measurements. However, I have found it unwise to fault Edmond for even 1^o in any measurement, or in any other way for that matter. Moreover, BOTH drag angles were increased.

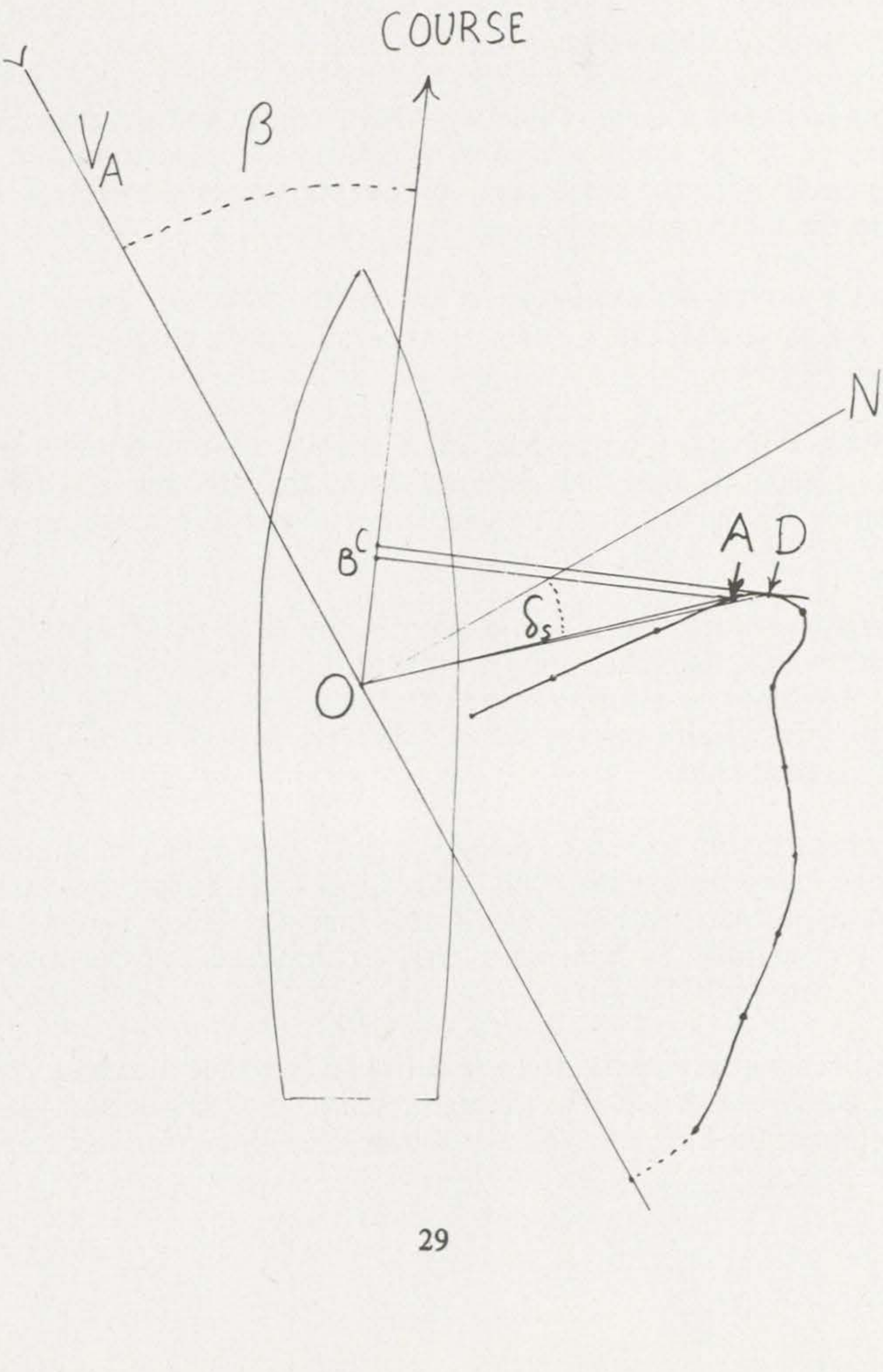
Next, I checked Harry Morss' figures for Galliard, given earlier in this publication. Minimum drag angles are given as:–Sail drag angle = 9^o. Hull drag angle = 10^o. At best V_{MG}, they are 11^o and 14^o respectively. Again, both are increased over the minimum, this time by 6^o for the sums. As will be explained later, this greater value is due to the use of the sloop rig on Galliard, as compared with the Una rig used by Edmond.

A near perfect explanation is shown in the diagram. The sail polar curve is drawn to the apparent wind on a boat. The minimum sail drag angle is shown by the line OA. This has a driving component along the course made good of OB, AB being at right angles to the course made good. However, the maximum driving component of the sail is given by DG, a line drawn at a tangent to the polar curve and at right angles to the course made good. This gives the driving component OC which is larger than OB. Harry Morss' figures for V_{MG}/V_T increase from 0.29 to 0.54 from minimum drag angles to best V_{MG}.

To complete this explanation, these angles should be mated up to the polar curve of hull resistances but there is not one in my references. One must assume that a similar thing happens to the hull to that given for the sails. Indeed, what happens in the water may be of greater importance than that which happens in air.

I call the above a 'near perfect' explanation because I don't know what happens in the water. There is an increase of leeway angle in Harry Morss' figures from 2½° to 5° from best V_{MG} to minimum drag angles which probably explains the great increase in V_{MG}/V_T from 0.29 to 0.54.

The sail polar curve in the drawing is that from Edmond Bruce. It will be noted that the stall is fairly abrupt. Harry Morss used the sloop rig which has a more rounded top to the polar curve and a less abrupt stall. This no doubt also explains why best V_{MG} occurs over a range of 10° for Galliard.



THE THAMES BARGE

by

John Morwood
Woodacres, Hythe, Kent, England.

One day, when our children were small, Pat and I took an afternoon off, got a baby sitter and went to Whitstable, on our own. Wandering about the harbour, we saw a Thames barge out at sea about half a mile off the shore. All sail was set but she did not appear to be moving. Suddenly, she turned towards us and steered straight towards the harbour.

I watched this magnificent sight for a while as she ran along the mole towards us. Suddenly, she stopped about 10 feet from the mole. We walked over to her and arrived in time to see the crewman winding a winch on the far side from us. I guessed that he was raising the leeboard and realised how the barge had been stopped – the leeboards had been dropped.

When the leeboard was up, a line was taken ashore and the crew then pulled the barge along by winding another winch on the mast to reel in the shore line. We could not wait any longer, but I suppose that the barge was winched right into the inner harbour by lines.

We often went to Whitstable after that in the hope of seeing more barges sailing. We never did, but we saw one barge having a cargo of wheat sucked out by an air pipe.

Since those days, the barge has often stirred me emotionally but I have never analysed the lines and sections. Now, the account of Dick Andrews "Whiffletree Research" has stimulated me to give the barge an evaluation. (See A.Y.R.S. 84B – July, 1976).

Dick's findings were that a box section as found in the Thames barge has a greater resistance than the round sectioned hull in light winds but that there is little difference in stronger winds and at great speeds. By its size alone, the barge must nearly always sail in what are scale light winds. Why then had she the hard chine?

Now, Frank Carr in his book "Sailing Barges" gives a bald account of a barge which had been built with round bilges, presumably on the basis of tank tests. As expected, this barge was faster than the chine barges – but only on running courses. To windward, her performance was disastrous and no more were ever built like her.

The only rational explanation of the above facts is that the chine is needed to produce lateral resistance. The chine, or near chine only occurs for about the middle-third of the hull, fore and aft of this, the hull section has a round bilge.

American readers will perhaps know of the New Haven Sharpie which has box sections from bow to stern, though with more flaring topsides than the Thames barge. This boat was often rowed and in any case lived in one of the light wind areas of the world. The hard single chine again must have been used for partial lateral resistance.

By contrast with the Thames barge and the New Haven Sharpie, the Dutch leeboard barges have round bilges. The work they do is much the same as that of the Thames barge but, in general, they are inland waterways craft which do not have to be dried out on beaches in shallow harbours. Nor do they often have to sail in very shallow water. My conclusion, until such time as we get a re-circulation test tank or other means to take drag angles, is that:

Shallow draft sailing craft can use at least a small section of the hull about midships with a near right angled V chine for lateral resistance.

THE THAMES BARGE HULL

The stern lines and sections show a reasonable and near yacht-like stern deriving from the box mid-section. Owing to the narrowness of the barge in relation to the length, the aft lines are fine and near streamlines up to the bottom of the transom.

The bow, by contrast is bulbous with a near half sphere shape. The Bruce Number of the Thames barge is only about 0.8 laden, 2.2 with no cargo which might be effectively less owing to the inefficiency of the sprit rig. One might say that the barge always moves slowly when judged by scale with a top speed not much better than 10 knots. This bulbous bow is no handicap at slow speeds. Indeed, it might even be an advantage as the 'Stagnation point' of the water flow at the bow might move onto the lee bow when there is leeway, thus giving a less asymetrical hull water flow when the craft is heeled. It would be analogous to the rounded leading edge of an aeroplane wing.

In all, the Thames barge is an example of the sailor's aphorism: "A cod's head and mackerel tail makes a ship which is sure to sail."

THE SPRITSAIL RIG

One of the things which rendered the Thames barge efficient in the days of sail was that two men could move a cargo of 100 tons through fairly long distances at an average speed of 5 to 6 knots. This has to be compared with the efficiency of a horse wagon. The only comparable transport were the collier brigs bringing coal from Newcastle to London, about which there is a big gap in my knowledge.

The reason why only a two man crew was needed was the sprit rig which, with its brails, reefs the large mainsail horizontally and thus easily towards the mast. The sail weighs about a ton so hoisting it would have been no easy job. In terms of drive per unit sail area, however, the sprit sail gives poor power with a coefficient of sail at about 0.8 This compares poorly with the 12 metre rig with a coefficient of 1.2 and, I guess, one for the semi-elliptical sail of about 2.0.

Uffa Fox at one time hoped to have a barge built with the "Wishbone Rig" and this would have been a great improvement. It was never done, alas but I hope that, one day, we will see a barge yacht, at least putting to sea with a semi-elliptical sail. The sail power would be doubled per unit area, pointing to windward would be very close and average times for courses would probably be halved.

As regards improving the barge hull, I have no suggestions. Probably, it is about as good as possible for its work. Stretching out the bow would increase top speeds. The tank might improve speeds by about 5%.

My final thought is that this particular article is written on a basis of informed guess work. How much better it would have been if it had been written on a basis of tank test and wind tunnel tests. Edmond Bruce has shown how a small yacht wind tunnel can be made. At present, I am working on a very similar re-circulation test tank. What I would like to do is to buy a Thames barge, build these two pieces of apparatus and set them up in the hold, live in the craft and both by myself and with the help of A.Y.R.S. members start a series of tests of various yacht hulls in which we all are interested.

References: Uffa Fox's Second Book, Page 140 – Giralda.
Frank Carr – Sailing Barges.

OPTIMUM WINDWARD PERFORMANCE

by

Jim Banfield
24 Garibaldi Street, Armidale, 2350, N.S.W., Australia.

The familiar vector equation:

$$\bar{V}_A = \bar{V}_T - \bar{V}_B$$

involves $\bar{V}_A$, $\bar{V}_T$ and $\bar{V}_B$, the vectorial velocities of the apparent wind, the true wind and the boat's speed (including leeway) respectively.

Fig. 1. For the direct estimation of V_{MG}, the component of V_B in the direction of the true wind, we require observations of the speed and direction of the apparent wind (direction relative to the true course) and the boat's speed. Since the apparent direction of the wind is normally measured with respect to the boat, two angular observations, this and leeway angle,

are normally required. Not only are these angles difficult to measure automatically and to translate into electric analogue signals, but analogue computation of V_{MG} from the four measurements is complicated and expensive to implement. Accordingly, automatic V_{MG} determination on board is beyond the reach of most dinghy and small yacht sailors.

Not usually recognised, however, is that we can optimise V_{MG} implicitly by the optimisation of the difference in the squares of V_A and V_B. Since, by the triangle formula (Fig. 1.):

$$V_A^2 = V_B^2 + V_T^2 + 2V_BV_T\text{Cos } \gamma$$

we find the required V_{MG} in

$$V_{MG} = V_B\text{Cos } \gamma$$

$$= \frac{V_A^2 - V_B^2 - V_T}{2V_T}$$

Maxima or minima in V_{MG}, corresponding to optimised sailing to windward or to optimised tacking downwind are, for a steady wind with V_T constant, found at the extremes of $(V_A^2 - V_B^2)$.

Both V_A and V_B are readily measurable electronically and a simple analogue device can be designed to compute and display the function $(V_A^2 - V_B^2)$. Moreover, a simple switch can force V_A to zero so that the same device can be used to optimise boat speed for reaching. Even wind and water vanes giving measures of V_A^2 and V_B^2 directly might be contemplated for a more primitive device.

We note that, for small changes in V_A and V_B of δV_A and δV_B,

$$\delta (V_A^2 - V_B^2) = 2V_A \delta V_A - 2V_B \delta V_B$$

When sailing close hauled, V_A is greater than V_B so that a change in sailing technique causing an increase in the apparent wind with no change (or better a decrease) in boat speed signals an approach to optimum V_{MG}.

When tacking downwind, an alteration increasing boat speed with V_A constant (or better a decrease of, V_A) is desirable.
At first sight, these conclusions seem contrary to "common sense" but then the "razor's edge" of optimum V_{MG} sailing is well documented in AYRS publications. However, rationalisation of these conclusions for two special cases is attempted below:

Fig. 2 1. AT CONSTANT BOAT SPEED. For example, a displacement hull at its hull speed.

To maximise $(V_A{}^2 - V_B{}^2)$ with V_B constant, we simply maximise V_A; for optimum downwind sailing, we minimise V_A. See Fig. 2.

Fig. 3a 2. SAILING AT CONSTANT HEADING TO THE TRUE WIND.

(a) When beating:– An increase in V_B will also increase V_A although not quite as much. However, since V_A is greater than V_B, the difference in squares will actually increase. See fig. 3a.

(b) Tacking downwind:– In this case, V_A is less than V_B so that an increase in boat speed will increase the square of V_B more than the square of V_A will increase, if indeed it does. See Fig. 3b.

Fig. 3c

(c) Beam reach:– Any increase in boat speed leaves the difference in squares unchanged; for $\gamma = 90^o$, $V_T{}^2 = V_A{}^2 - V_B{}^2$. We know how easy it is to foot too low and get no further to windward! See Fig. 3c.

Frank Bethwaite in "Faster Sailing," 1975 a Modern Boating publication, gives a prescription for optimum speed to windward under specified conditions which stated essentially that, for displacement hull sailing, one should watch the stern wave and should its peak go aft of the transom, one should point higher until the wave crest is brought back to the transom position. This advice accords with case 1. above.

Letter from John A. Bennett, 7405 Denton Road, Bethesda, Maryland 20014.

To John Morwood.

Dear Mr. Morwood,

In your article, "The Quest for the Ultimate Yacht" (Chapter 32 of **Design for Fast Sailing**) you offer several criteria by which one might define an ultimate yacht, but discuss only No. 1, maximum speed for a given sail area. I should like to suggest that a more appropriate criterion would be maximum speed under the widest possible range of wind conditions. Limitations on sail area are necessary for racing classes, but not for an "ultimate" yacht. I bring this up because it appears that small boat sailors, even AYRS members, have a certain mind set towards boats of relatively fixed sail area, and this has limited the amount of innovation relating to methods of changing sail area.

Regardless of the type of boat, maximum speed can be obtained for only a limited range of total sail force. If the sail area is inappropriate for the wind speed, so that the sail force is either more or less than the optimum range, the performance suffers. Most small boats do not have nearly enough range in sail area to accommodate properly to a reasonable range of wind speeds, and this limits overall performance far more than any lack of sail efficiency at a particular wind speed.

For example, if one wished to keep the sail force constant for wind speeds from 5 to 25 kt, the sail area would have to change in the ratio of 25 to 1. Because the boats that most of us sail are not equipped for anything like this range, they spend much of their sailing time either loafing along in light winds or being overpowered in heavy ones.

Despite all the material on sail rigs that has been published by AYRS, there seems to have been relatively little attention to this problem of convenient means for changing sail areas by large ratios while maintaining decent efficiencies. The junk rig, which is about the best currently available for large reefing ratios, doesn't score very high on efficiency under any conditions. Possibly the rig that you proposed in the chapter referred to earler – a semi-elliptical sail on curved yards–might be a worthwhile approach, but I have not seen reports of anyone having tried it.

I believe that there is an opportunity for important contributions to this problem, and I hope that AYRS members will try to develop some new ideas and designs.

John A. Bennett

Letter from Frank R. Bailey, RD 5 Box 479, Sewickley, Pa. 15143, U.S.A.

Cross section of a Test Tank using 4 foot by 8 foot plywood.

The basic cross section of a test tank could be for convenience one foot deep by two feet wide. Two more sections are possible using only two longitudinal joints and the original cut sizes.

(a) Slope the sides 21 degrees outward. This would give the maximum cross sectional area. It works out to 10 per cent more water in the tank.

(b) Slope the sides 42 degrees outward. This cross sectional area would be the same as the vertical sides.

In (a), there would be a surface width of 2.72 feet for a drop in water level of about ¾ inch. In (b), there would be a surface width of 3.34 feet for a drop in water level of about 3 inches. These are the most convenient shapes. Probably the best theoretically would be 4 strips, one foot wide, tangent to a semi-circle. However, this would be harder to support and build. If you are geometrically inclined, other strip widths will suggest themselves, keeping in mind the necessity of maximising the ratio of cross sectional area to wetted perimeter.

Frank R. Bailey

TREP ANALYSIS OF CHAMPION OF THE SEAS' ONE DAY RECORD RUN

by
Richard Boehmer
107 Crescent View Avenue, Riverside, R.I. 02915, U.S.A.

For over a century, both armchair theorists and experienced seamen alike have seriously questioned the fastest day's run ever made under sail of 465 n. miles as claimed by the CHAMPION OF THE SEAS on her first voyage from Liverpool to Melbourne. The evidence of this record lies solely in the ship's newspaper of December 15th, 1854, as her official log is reported missing. But also missing are the official ship's logs of the next nine fastest runs claimed: FLYING SCUD, 449 n. miles in 1854; MARCO POLO, 438 n. miles in 1854; LIGHTNING, 436 n. miles in 1854 and 430 n. miles in 1857; JAMES BAINES, 423 n. miles in 1855; again LIGHTNING, 421 n. miles in 1854; DONALD McKAY, 421 n. miles in 1855; RED JACKET, 421 n. miles in 1854; GREAT REPUBLIC, 413 n. miles in 1856. If one were to disclaim CHAMPION OF THE SEAS' run solely because of the lack of "official" evidence, the ship's log, these other claims would likewise have to be ignored. Although some disbelievers would throw out all claims over 400 n. miles, ignoring the above claims would not be a reasonable thing to do. Short of going back in time and being upon the decks of the above clipper ships or of building and sailing full scale replicas of them, an alternative means of investigation is an armchair approach of using documented or well-accepted runs of greater duration and therefore slower speeds to mathematically project a probable day's run that could be compared to the CHAMPION OF THE SEAS' 465 n. miles claim.

This projection of a probable day's run is possible through a mathematical technique called Time Related and Equivalent Performance (TREP) which presents a sailing vessel's performance not simply as her speed but as a set of everage speeds coupled with the respective periods of time over which these speeds were calculated. The TREP of a sailing vessel is a line determined by a linear analysis of a set of paired logarithms of both her average speeds (knots) and time periods (hours) over which the speeds were obtained. When plotted on full logarithmic paper, a sailing vessel's TREP is a straight line. Any point along this line represents a time related average speed that is equivalent in performance to any other point on the line, which is the average speed for a different time period.

In effect, TREP takes into account the variability of weather and sea state which prohibits a sailing vessel from maintaining during and entire passage the higher speeds that she is capable of reaching for shorter durations. It follows that for any time period sampled within an entire sailing passage, an average speed can be found that is higher than that of the entire time period, likewise even higher average speeds can be found in further subdivisions. Of course, a vessel's hull speed will limit in most cases this observation and similarly the application of TREP.

Prior to examining the records of clipper ships, TREP lines were determined for two modern yachts whose sailing records are well-documented and therefore relatively beyond question. This was done in order to determine what difference could be expected between the claimed, best daily runs of these yachts and the projections by TREP analysis.

The first modern yachts investigated was Sir Francis Chichester's GIPSY MOTH IV with which he single-handedly sailed the clipper route around the world from Plymouth to Sydney and back to Plymouth. After examining many pairs of sailing periods and their corresponding average speeds, GIPSY MOTH'S TREP line was calculated using four of her best runs: the entire circumnavigation of 29,630 n. miles logged in 226 days, the 13,750 n. mile first leg from Plymouth to Sydney in a little over 106 days, a 5 week run of 5,230.5 n. miles, and an 8 day run of 1416.5 n. miles. These four time-speed points lie very close to their resultant TREP line (see Figure). Their correlation coefficient of 0.9692 indicates that her performances within these periods was very consistent. The equation of GIPSY MOTH'S TREP is:

$$S_T = 10^{(1.0779 - 0.0949 \log T)}$$

where S_T is the average speed (knots) over the time period, T (hours). This TREP projects a possible day's run of 212 n. miles which is about 6% higher than Chichester's claim of a probable 199.8 n. mile run in 24 hours (23 hour, noon to noon, down easting run of 191.5 n. miles).

The second modern yacht investigated was MANUREVA (see PEN DUICK IV), the 70 foot aluminium racing trimaran, built for Eric Tabarly. In December, 1968, Tabarly sailed her 2,600 n. miles across the Atlantic from Tenerife in the Canary Islands to Fort de France, Martinique in 10 days 12 hours, thereby establishing the transatlantic crewed yacht record. During this record passage, PEN DUICK covered 930 n. miles in 3 days, an average speed of almost 13 knots. Six months later, she set another unbroken yacht record of 8 days 13 hours 9 minutes for the 2225 n. mile passage from San Pedro, California to Diamond Head, Hawaii. After winning the Royal Western/Observer Singlehanded Transatlantic Race, PEN DUICK's new owner Alain Colas, renamed her MANUREVA and commenced to sail her singlehandedly, 29,600 n. miles around the world in 169 days, leaving and returning to St. Malo, France and stopping only at Sydney. A TREP analysis of these four record runs yields a line to which the time-speed points more closely fit (correlation coefficient of 0.9988) than GIPSY MOTH's data fit her TREP line. The equation of MANUREVA's TREP is:

$$S_T = 10^{(1.3568 - 0.1363 \log T)}$$

that projects a possible day's run of 354 n. miles which is about 8% higher than Colas' claim of 326 n. miles recorded during his circumnavigation.

Although the above two yachts differed greatly in design, both of their best daily runs were from 6 – 8% less than their TREP projections indicated; therefore similar results would be expected for other sailing vessels, particularly a clipper ship.

Since there is little mention of the CHAMPION OF THE SEAS other than her 24 hour record, it was decided to examine the record passages of many clipper ships to find the best six runs over diverse periods of time to be used for calculating a TREP line that would represent the best of the clipper ships as a class. After all, most opponents to CHAMPION OF THE SEAS. record have basically questioned the ability of any clipper ship to have made such a daily run, even though many were known to have sailed at speeds in excess of the 18 knots necessary for a day's run of 465 n. miles.

Two of the six best clipper performances were made in 1854 – 1855 by the JAMES BAINES on her passage around the world from Liverpool to Melbourne and back, a round distance, conservatively estimated at 26,000 n. miles (RED JACKET logged 13,880 n. miles during her 1854 record run of 67 days 13 hours from Liverpool to Melbourne; LIGHTNING logged 12,150 n. miles during her 1854 record run of 63 days from Melbourne to Liverpool). JAMES BAINES made the total circumnavigation in 127 days under sail, 58 days out and 69 days back. Her entire passage and the first leg are her two best performances used for the TREP analysis.

Surprisingly, LIGHTNING'S famous 63 day return run from Melbourne does not reflect an equivalent performance to JAMES BAINES' two best runs and subsequently falls below the resultant TREP line as do many other, famous, long distance records. The quick passages to and from the Orient by ARIEL, BEVERLY, CUTTY SARK, SWEEPSTAKES, THERMOPYLAE, and the WITCH OF THE WAVES and the roundings of Cape Horn between the East and West Coasts of the United States by ANDREW JACKSON, COMET, CONTEST, FLYING CLOUD, GREAT REPUBLIC, NORTHERN AMERICAN, and YOUNG AMERICAN all fall below the resultant TREP line. Also, not nearly fast enough to be considered were the slower but consistent passages of the great, five masted, steel barks of the German Laeisz P-line, nor their five masted ship, PREUSSEN.

The next two passages, figured to be among the best six were made by the wooden clipper, RED JACKET, and the iron clipper, MELBOURNE. In 1854 RED JACKET sailed by the Cape of Good Hope on to Melbourne, a distance of 5,579 n. miles, in 19 days 16 hours. Also on her way to Melbourne, but twenty one years later, MELBOURNE ran her easting down in strong westerly gales and sailed 5,100 n. miles in 17 days.

The fifth remarkable record run was made by the SOVEREIGN OF THE SEAS. While sailing from Honolulu to Cape Horn, she ran 3,562 n. miles in 11 days due once again to westerly gales. Comparably, this record run easily betters RED JACKET'S famous, 1854 transatlantic crossing from

New York to Liverpool of 3,332 n. miles in 12 days.

The sixth best run that was chosen from all the rest was made by the composite clipper, CUTTY SARK. Her 6 day run of 2,163 n. miles was logged during her 1875 passage through the Roaring Forties on her way to Sydney. The next best 6 day run on record was RED JACKET's 2,020 n. miles when setting the transatlantic record previously mentioned.

The resultant TREP line of these six superior, clipper ship runs (correlation coefficient of 0.9957) whose equation is:

$$S_T - 10^{(1.5736 - 0.1840 \log T)}$$

projects a possible day's run for a clipper ship as 502 n. miles, a good 7% higher than the claim of CHAMPION OF THE SEAS. As if the result of this TREP analysis is not enough, one should note that (1) She was in the right place at the right time, i.e. the Roaring Forties in 1854 – 1855. (2) Only eight months had passed since her launching and therefore her bottom would have still been clean and smooth, (3) She was on the lightly loaded, outbound run to Australia that was generally the fastest half of the circumnavigation, (4) She was considered an improvement upon LIGHTNING in beauty of model, strength of construction, and some other elements of perfection, (5) She had proven her exactness of sailing quality to the JAMES BAINES when they left Portsmouth together carrying the same number of troops bound for India, and they arrived within a few hours of each other after racing for 101 days.

If any claim is to be questioned, LIGHTNING's 10 day run of 3,722 n. miles is a much easier target for criticism, for it is the only claim that was found to lie above the unquestionable six best, clipper ship runs and their resultant TREP line. By accepting LIGHTNING's 10 day run or any other that lies significantly above the TREP line, more not less credibility is given to CHAMPION OF THE SEAS' record of 465 n. miles in one day.

REFERENCES:

Boehmer, Richard, 1977. Multihull Ocean Racing, Boehmer Publishing, Riverside, Rhode Island, 184 p.

Chichester, Sir Francis, 1969. Gipsy Moth Circles the World, Pocket Books, New York, 298 p.

Clark, Arthur H., 1910. The Clipper Ship Era, G.P. Putnam's Sons, New York 404 p.

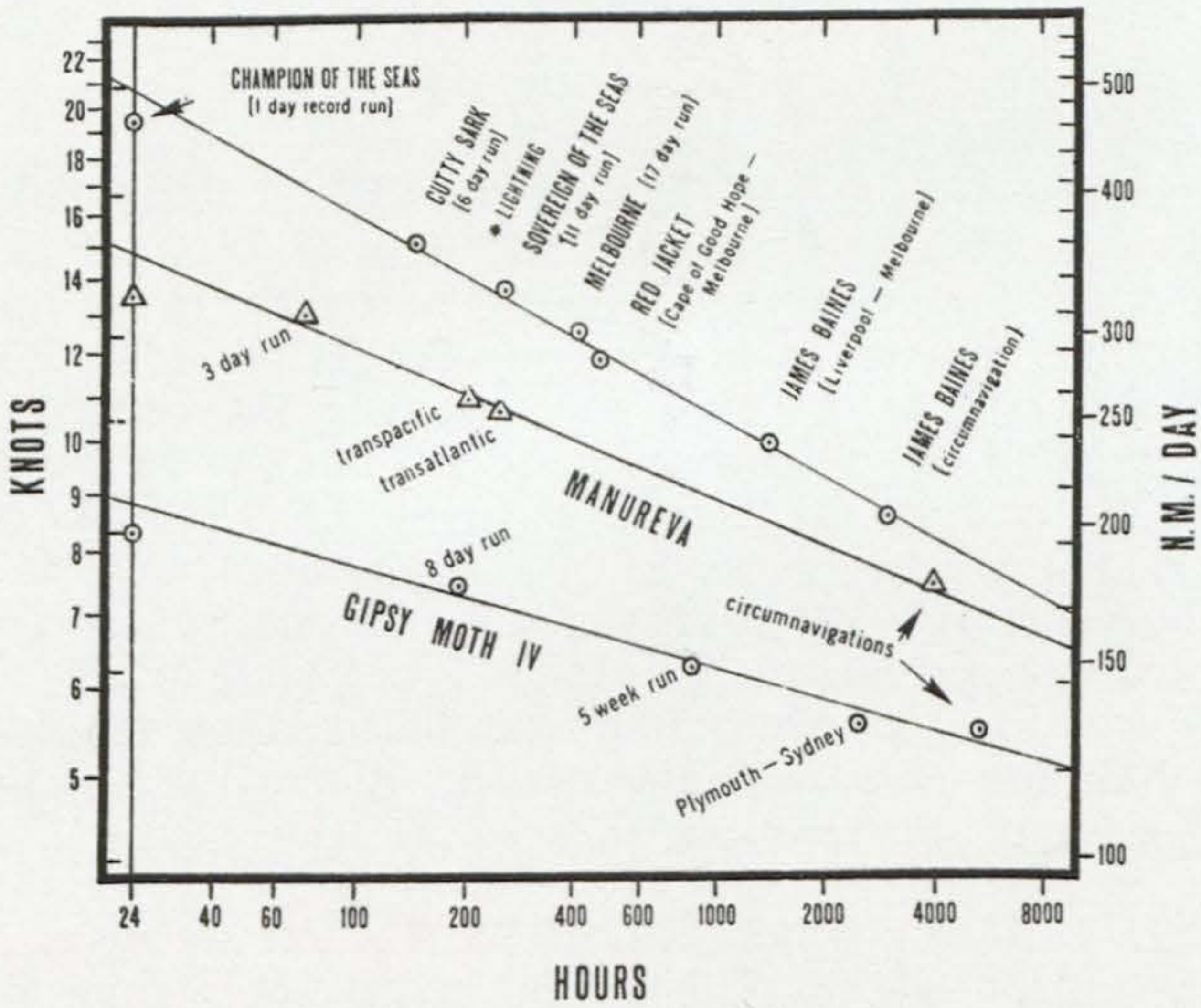
Clarke, D. H., 1975. An Evolution of Singlehanders, Stanford Maritime, London, 206 p.

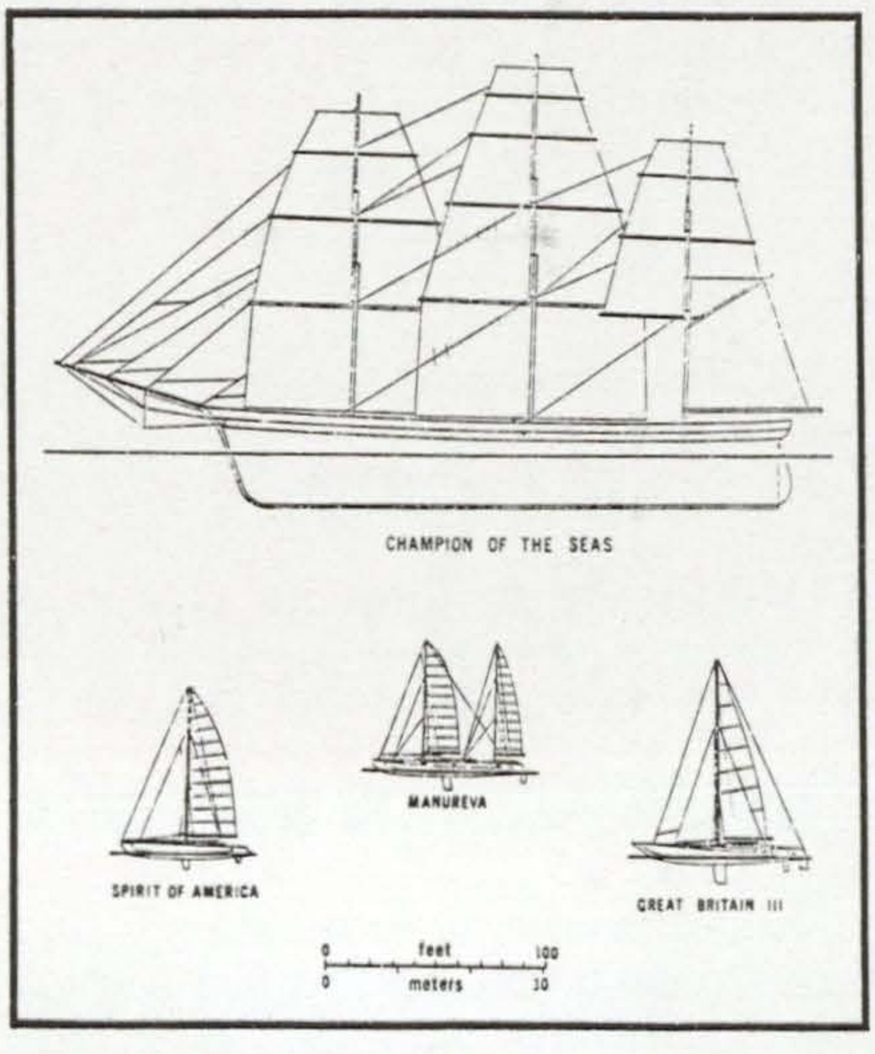
Culter, Carl, 1930. Greyhounds of the Sea, Halcyon House, New York, 592 p.

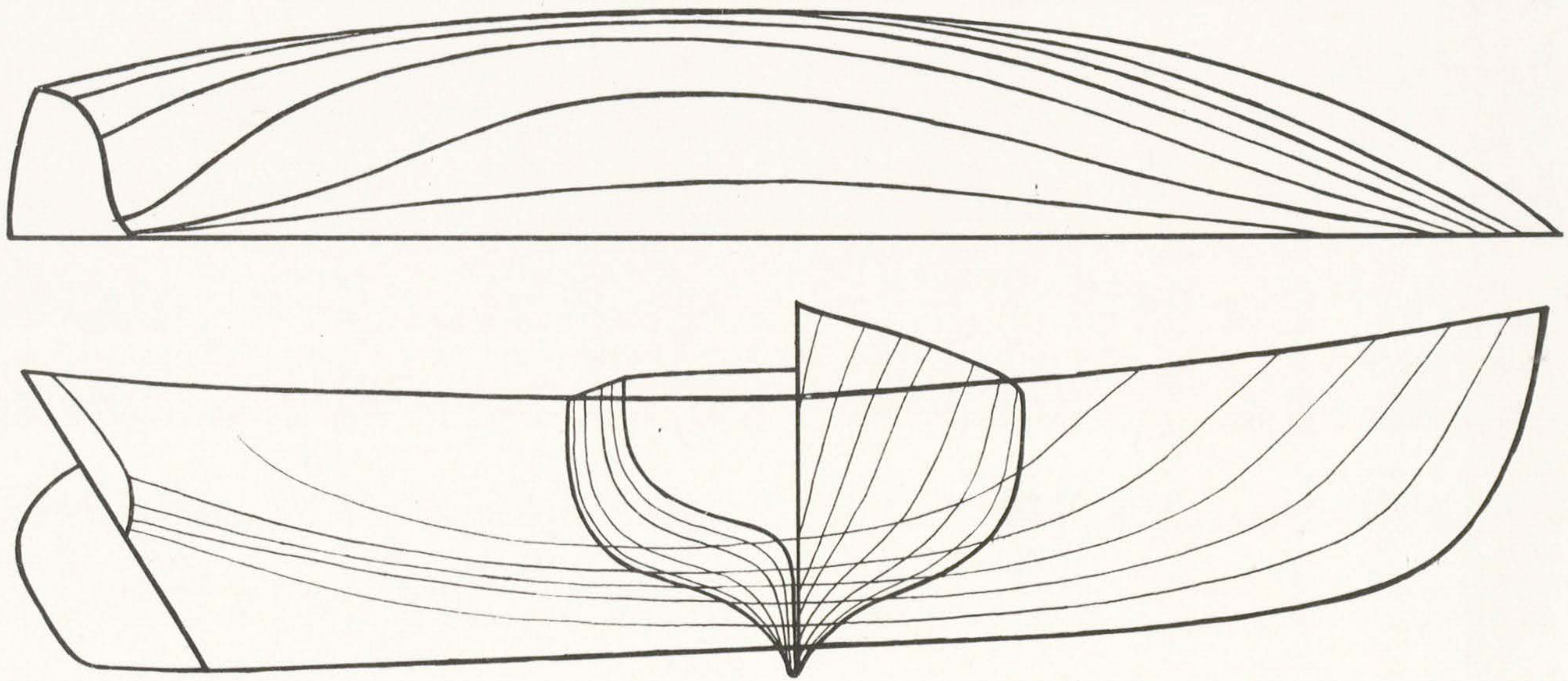
Culter, Carl, 1952. Five Hundred Sailing Records of American Built Ships, The Maritime Historical Association, Mystic, Connecticut, 114 p.

Learmont, James, 1957. Speed under sail, The Mariner's Mirror, 43 : 3, 225–231. (and associated notes in 43 : 4, 341–342 and 44 : 1, 64–69.
MacGregor, David, 1952. The Tea Clippers, Percival Marshall & Co., Inc., London, 272 p.
McKay, Richard, 1969. Some Famous Sailing Ships and Their Builder Donald McKay, 7 C's Press, Riverside, Connecticut, 396 p.
Villiers, Alan, 1953. The Way of a Ship, Charles Scribner's Sons, New York, 429 p.

TREP LINES

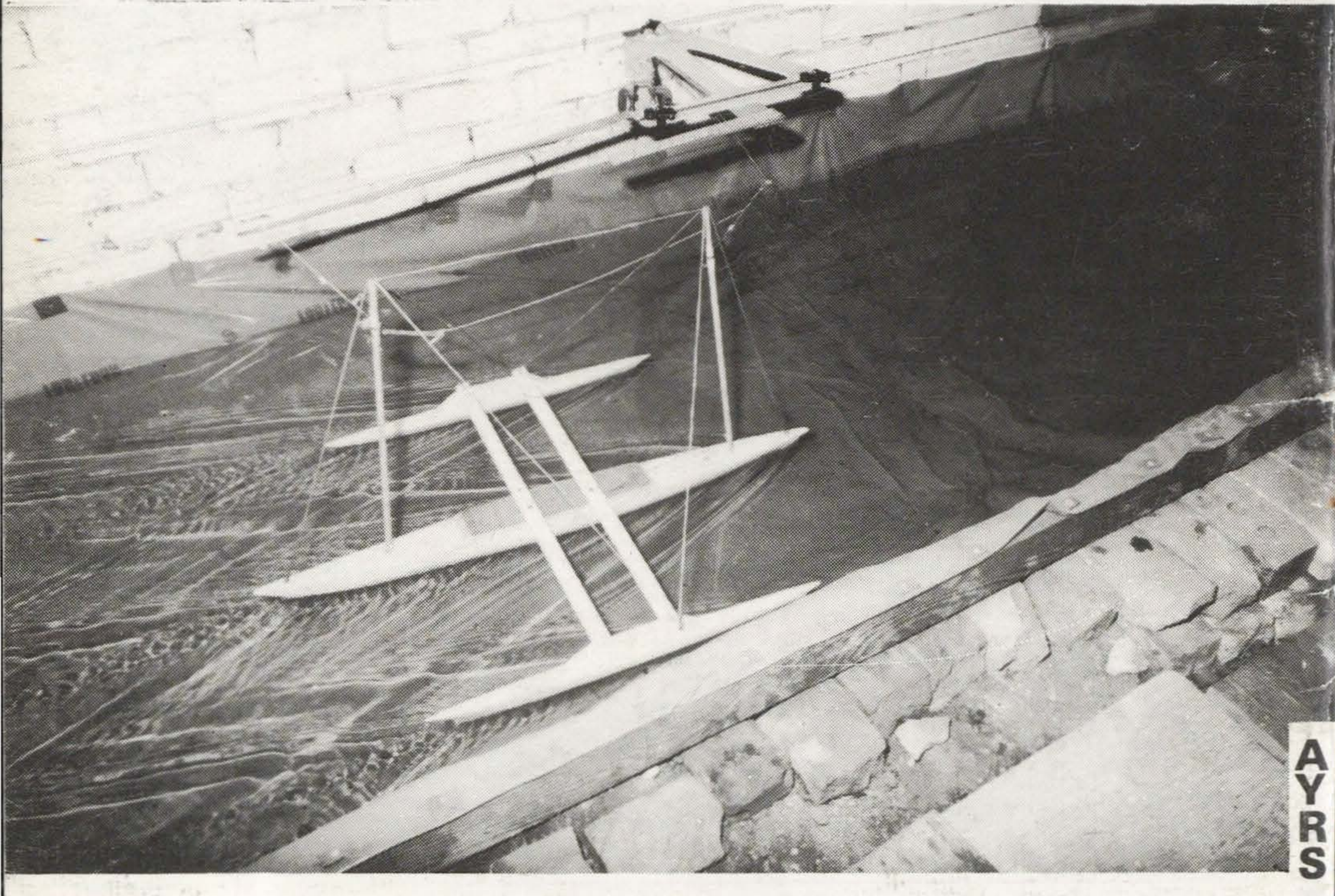






Lines of "Freedom 40"

A simple Tank for Model Comparison made by Josef T. Dusek, Sydney.



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