SAILING ANALYSES

A.Y.R.S. PUBLICATION **No. 61**

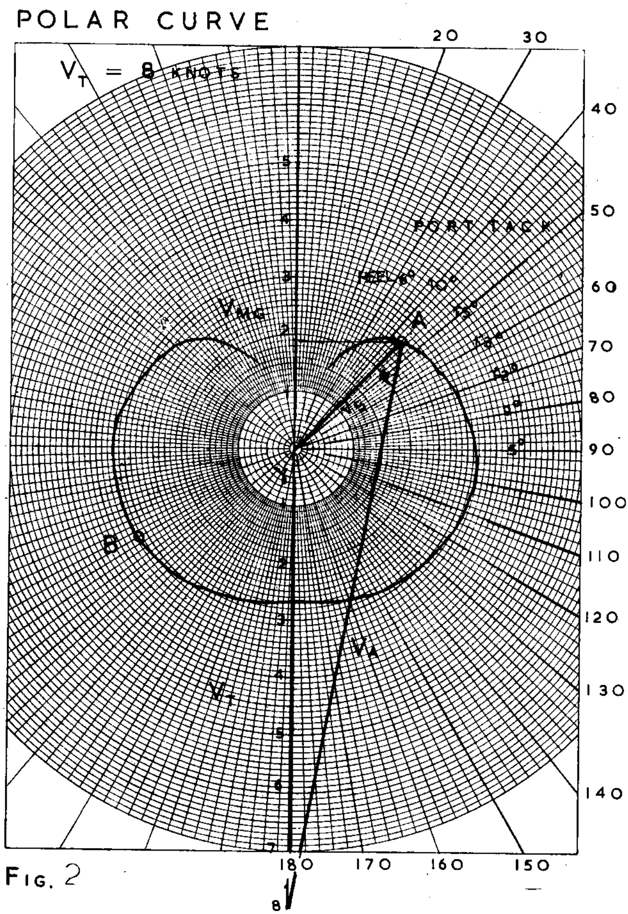


FIG. 2

CONTENTS

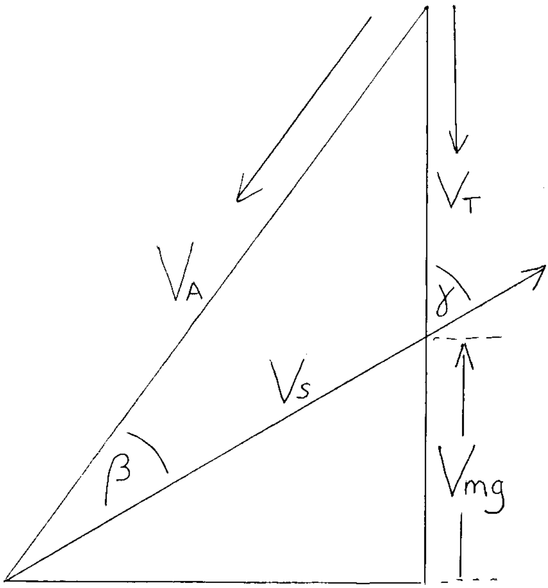
THE AMATEUR YACHT RESEARCH SOCIETY

(Founded June, 1955)

EDITORIAL

July, 1967.

This publication contains some technical articles which we hope most of our readers can understand in general, if not in all details. We again list the symbols used but at the beginning of the Editorial for easy reference.



Yacht Research Symbols Proposed

True Wind Velocity knots	V_T
Apparent Wind Velocity knots	V_A
Velocity of ship, knots	V_S
Angle of Course to apparent wind	β (beta)
Leeway angle (between ships head and course)	λ (lambda)
Angle of ships head to app. wind	β-λ
Angle of ships Course to True Wind	γ (gamma)
Angle of heel	θ (theta)
Angle of foresail to centre line of ship	δf (delta f)
Angle of mainsail to centre line of ship	δm (delta m)
Coefficient of lift	C_L
Coefficient of Drag	C_D
Driving force	F_R
Heeling force	F_H
Velocity of ship made good to windward, knots	V_{mg}.

Pierre Gutelle adds:-

α = angle between the sail and the apparent wind.
ε = angle of the resultant R (the sail force) with the axis of of the boat.
R = the resultant sail force.

Edmond Bruce uses:

P — pressure (normal).
F — friction (tangential).
L — lift.
D — drag.
T — total or true.
A — apparent.
S — sail.
H — hull.
B — complete boat (S already used for sail. We sail boats not ships).

These subscripes were applied to:

V — velocity in knots.
v — velocity in feet per second.
F — force in pounds.
R — resistance in pounds.
W — weight in pounds.
δ — drag angle in degrees. (Greek for angles).
C — aeronautical type of coefficient.
K — simplified but differently defined coefficient.

Extraordinary A.Y.R.S. General Meeting on July 18th, 1967. We still have some tickets left for this meeting at £1 each and members may now apply for additional ones.

Winter Meetings 1967-1968. The dates for these meetings are as follows, though speakers and subjects have not yet been chosen:-

Tuesday 3rd October, 1967.
" 7th November, 1967.
" 5th December, 1967.
" 2nd January, 1968.
" 6th February, 1968.
" 5th March, 1968.
" 2nd April, 1968.

We must apologise for getting the date of our last meeting wrong. All A.Y.R.S. meetings are on Tuesdays and all for this coming winter are on the first Tuesday in each month.

A Devon A.Y.R.S. Group. Fred Benyon-Tinker, 49 Pillar Gardens, Northfield Lane, Brixham, Devon would like members in the area to contact him with a view to forming a local group. It will be remembered that Fred started a Surrey Group years ago and got the Weir Wood Meetings going. Devon members and all who can get to Brixham can be assured of lively and interesting meetings.

PUBLICATIONS OF INTEREST TO MEMBERS

S.U.Y.R. Report No. 17. "*Tests of a* 5.5 *meter Yacht Form with various Fin Sweepback Angles,*" *by K. MacLaverty.* Available from Dept. Aeronautics, University of Southampton, Hants., England. Price 5 shillings. This shows that the drag angle of the hull is reduced by increasing the sweep back angle to 60° from the vertical, when it is still decreasing rapidly. The minimum angle was, however, 22°. There is obviously a long way to go to get the 10° yacht with a hull drag angle of 5° but it looks as if improvement can be obtained from greater sweepback angles than are used at present, thus approaching the low aspect ratio keel.

"*Resistance Experiments on High-speed Displacement Forms,*" *by Hugh Y. H. Yeh.* David Taylor Model Basin, Washington D.C. Availability not known. This paper tells of experiments with catamaran-like hulls of different shapes and different beam-depth ratios, block co-efficients and displacement-length ratios. It is obviously good stuff but the material is so set out that I cannot understand it. Perhaps someone would extract the meat of it for us.

Hydrofoils by Christopher Hook and Kermode. Pitmans 32/6. This gives gives an account of motorised hydrofoil craft and is written in a simple and non mathematical style.

Yachts and Yachting will shortly have an article on the problems of hydrofoil sailing by Hugh Barkla and Christopher Hook.

I.A.B.B.S. This Society was started by Jim Betts, 1535 W. Farwell Ave., Chicago Ill. 60626 to help amateurs find places to build boats and to help them with advice and plans.

Multihull Races. We have been sent notices of two races for multihulls too late for inclusion in the April publication. These are as follows:

First International Cruising Multihull Race—U.S. to Bermuda. This will have been run on 25th June. Organisers: I.M.B.R.A., 39 Steppingstone Lane, Kings Point, L.I.

Offshore Race for Multihulls in the Irish Sea. Round the Isle of Man. This will have been run on 28th May. Organisers: Manx Sailing and Cruising Club, Briarfield, Ballajora, Maughold, Isle of Man.

Misnumbering the April Publication. This got labelled No. 66, instead of No. 60, owing to the compositor misreading my longhand writing and my failing to pick up the mistake. This may cause confusion in the sets of publications which so many people keep. People can alter the number on the last publication and the publication which would have been numbered No. 66 will be No. 66A, or 6A6. I must also apologise for the last publication being late. To assemble and edit the present size of A.Y.R.S. publication single-handed is quite a bit of effort and there are many letters to write, and things to organise. Sometimes, alas, both my energy and time don't exist owing to an unfortunate necessity to earn my living and the publication gets behindhand, though never as late as this. However, there was a hold-up at both the printers and distributors for this issue.

CRUISING YACHT DESIGN COMPETITION 1968

Prizes: First £50. Second £20. Third £10.

The Objectives: To improve the seaworthiness, speed and ease of handling of short handed ocean cruising yachts by competitive sailing trials of scale models of the yacht designs entered. The models must not be more than 36 inches long or have more than 500 sq. inches of sail area. The detailed rules for the competition can be got from Woodacres.

This will be the third year we have run this competition and so far, it has been very instructive in design points. However, we must have more models in future to make it the exciting event it should be. Low aspect ratio hydrofoil stabilisers instead of floats could be made or even complete hydrofoil craft. The Mclachlan or James Wharram hulls are easy to build and obviously fast so why not have a go?

* * *

SAILING ANALYSES

The non-technical member should read this publication backwards. Bernard Rhodes concludes this publication with his letter written in mid-Atlantic on his trimaran *KLIS*. Arthur Piver before this tells of the simplest navigation method, using the sun, while *PELORUS JACK II* and "The Inventor's Art" should please most people in some way or another. John Hogg's examination of the "Multihull Breakaway" and methods of cure is far from theoretical, while Fin Utne's letter and calculations that a windmill-propellor boat could be fast will please some.

Aeroplanes, Geese and Sails by R. R. A. Bratt deals with a matter which has concerned many a sailor in the past while my analysis of twin bilge keels and Edmund Bruce's comments could set people thinking about this interesting matter.

The more technical member will find this publication rather a mixture of facts and analyses. The most amazing thing is, however, the continued absence of a figure giving the complete yacht performance of which two types are necessary as follows:

For the Helmsman. On any heading to the apparent wind, in any apparent windspeed, a helmsman should be able to find out quickly, from a figure, the greatest speed previously achieved by that yacht and the angle of heel at which it occurred. I think this could be drawn as a series of concentric polar curves with the heel angles marked along them. Each polar would be the sailing performance at a fixed windspeed and the windspeeds would be chosen either to spread the curves appropriately or to be of most value to the helmsman.

For the Analyst. At any angle between the true wind direction and the course made good, in any true windspeed, the speed and heeling angle should be available. Again, I think this could be drawn as a series of concentric polars.

The uses of the curves is more or less self evident. The helmsman would quickly know if his yacht was not performing up to her maximum and that sail adjustment was necessary. The sailing analyst could compare one yacht with another on all aspects of performance, and estimate the value of changing one sail for another. Of course, we do not expect to see such curves for 12 meters at the moment but all *ONE DESIGN* yachts could well be studied thus.

The "Portsmouth Yardstick" as a Research Tool. It would be an interesting exercise to graph length, beam, sail area, weight and possibly wetted surface against the Portsmouth Yardstick number, which is an index of speed. The trends shown in such a graph would be of great interest in studying yachts.

WIND FLOW MEASUREMENT AND DESCRIPTION

BY

J. Hogg

Parklands Cottage, Curdridge, Southampton

In his "Wind and the Sails" article in Publication 57 John Morwood rightly stresses the need to interpret and describe what is indicated by measurement. In the case of wind study I must confess that the more one measures the more one is at a loss to describe adequately without over-simplification. Much work and many papers have been devoted to the subject but there is still room for more experiment and

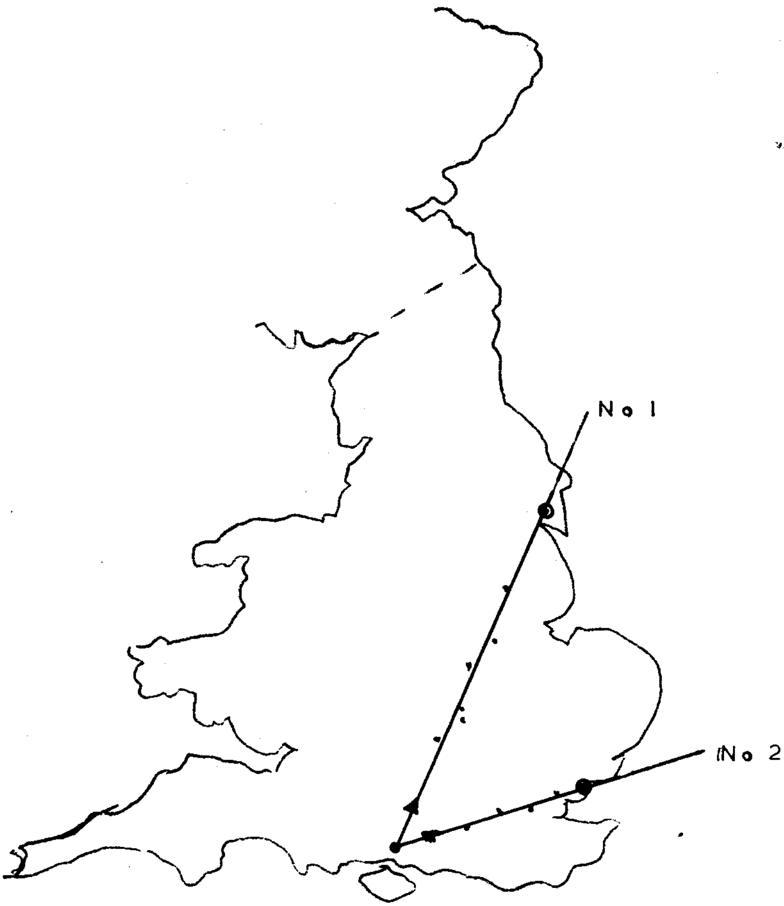


Fig. 1. Tracks of balloons

deduction. Since the whole aspect of sailing is bound up with the wind's behaviour, it is worth while continuing to remeasure and redescribe, and to continue to exchange ideas. There is a growing need to study the character if the natural wind round yachts' sails and to compare its effects with those of the artificial wind in the Tunnel. The following notes refer to some attempts to get a closer first hand acquaintance of sailing wind flow, helped by measurement. They are meant to supplement the wind graphs which appeared in Publication 56.

General Wind Flow. In spite of the vagaries of the wind the flow across the country can be surprisingly consistant. On several occasions the tracks of balloons we have released over a number of hours have been found to have travelled across England in a straight line with very little spread. Fig. 1 shows the tracks on two typical occasions, determined by the landing points of the balloons. This gives us a picture of wind flow at several hundred feet sweeping across the country in

The Aberdovey Tower

long steady paths for hours at a time until a gradual swing or a shift occurs, due to a number of possible causes.

Lower down at 30 feet (or 10 metres, the standard meteorological measuring height) the same picture occurs, particularly at sea where surface interference is low. Fig. 2 shows an example of the wind at this height, the chart showing a steady wind direction of 210° and a steady mean speed of 22 knots. But here can be seen clearly the rhythmic rise and fall in speed and repeated minor changes in direction which characterise the natural wind (in contrast to the streamed unchanging "draught" in a windtunnel). The recording of these variations requires a faster and more sensitive chart than the one in Fig. 2. Recently I used such a recorder to measure the wind flow over water at heights up to 25 feet. Some of the tests were made at Aberdovey, a wide beautiful estuary in Wales. There was fortunately a lightly built tower set some two miles out in the estuary and tests were made at various heights over the sea with a perfectly clear fetch from the Atlantic. Recordings were made with the wind vane spark-recorder and charts taken with the vane in the vertical and also in the horizontal positions, and these produced the evidence of the rolling tubulence, which John Morwood commented on, occurring in both planes and in fact in any plane in which the vane was held. The "bundles" of wind are driven along rolling and turning so that a sensitive flow gauge can detect the difference between the oncoming and retreating fronts amongst the mean flow.

In addition recordings were taken on the long beaches, again in various planes. Here of course the turbulance was even more pronounced due to the drag over the ground. On some days the flow of blown sand along the beach could be seen as it followed the typical snakey paths. These paths are really the tracks of sand particles which are rotating in "bundles" or eddies while they travel with the general flow. The speed of rotation increases as the wind speed increases. Their rotation cannot be seen because of their general velocity, and they tend to "stream" when near the ground.

This can also be shown by watching the tracks of bubbles when blown in a wind by means of the "bubble gun." The groups of bubbles travel with the wind but are constantly changing their positions one with another. Their rotating movement is masked by the faster mean wind flow and this produces the complicated snakey courses. The occurrence of similar turbulance in other planes contributes to the complication but the principle is still reatined—that of rolling and revolving bundles within the general air stream.

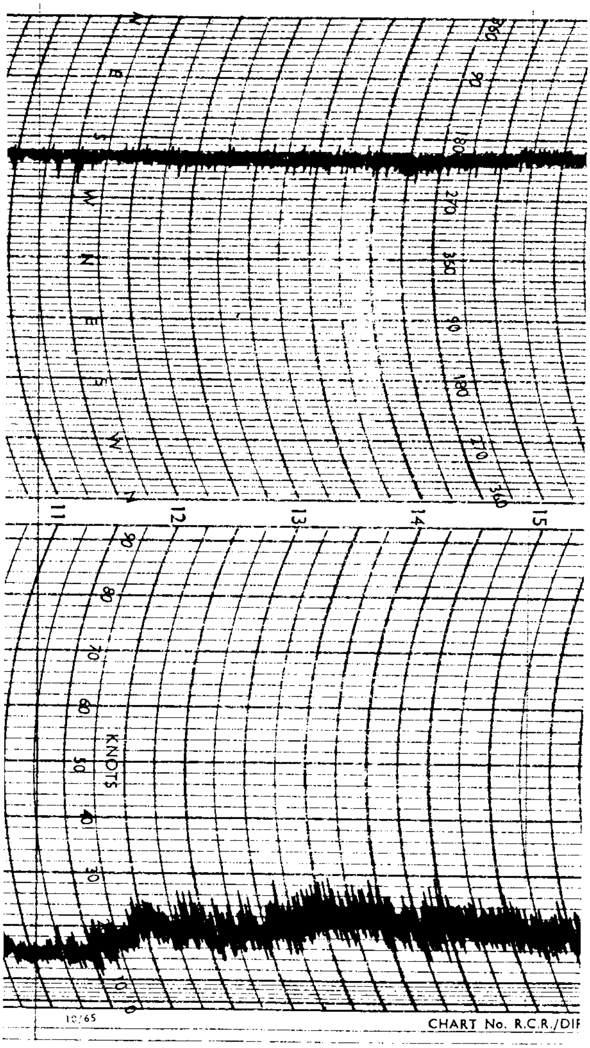


Fig. 2 Section of recorder chart from weather station showing steady wind direction over 5 hours at fairly steady wind speed. (Taken at 30 ft. above sea.)

On Board.

Considering now a yacht sailing into this turbulent wind flow, the effect of the yacht's forward speed (when close hauled) does not reduce the size (or amplitude) of these wind eddies but it does increase their apparent speed of arrival and they appear to the yacht to be more bunched because of this. The *character* of the wind has changed as a result of the yacht's velocity. Fig. 3 illustrates this. It is a tracing of

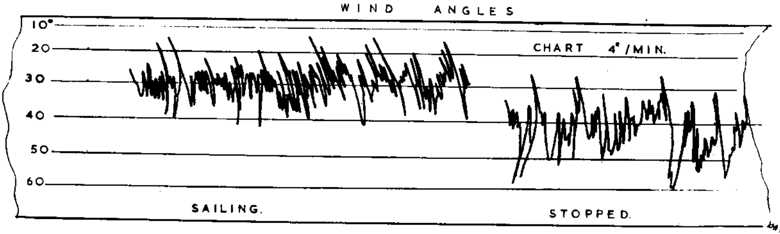


Fig. 3. Wind direction on the same compass bearing—Right when starting, Left—sailing

a chart from a wind angle recorder mounted on an 18 foot C.B. yacht, firstly when stationary (sheets flying) and immediately afterwards when sailing along on the same compass bearing (i.e. keeping the same angle to the True wind). On the right hand end of the chart the wind is True because the yacht has no forward motion. The average wind angle is 44°. On the left hand section of the chart the yacht is sailing and the wind is coming from closer ahead and its speed has increased (i.e. the Apparent wind) the wind angle now averaging 29°, and the speed being now 10 knots. At the same time the bunching effect on the wind bundles (i.e. the apparent speed of encounter) has increased. This is evident from the closer spacing of the variations on the chart which changes from approx. 1.7 cycles per second on the right hand to 2.2 c/s on the left hand side of the chart. This agrees with the calculated prediction of this effect, although it is not easy to measure complete cycles even on the original chart. Still the effect is clearly seen. The conditions at this stage were $V_A = 10$, $V_T = 8$, $V_S = 2.6$., $\beta - \lambda = 29°$, $\lambda = 5°$, $\beta = 34°$, $\gamma = 44.5°$, $\theta = 10°$, $Vmg = 1.85$.

Other measurements on board (bubbles, fans, streamers etc.) help to form the picture of the yacht heading into this natural stream of turbulent wind flow which advances on the sails with its "side bands" coming in at different velocities and directions. Part of this stream flows along the weather side of the sails, reducing in speed as it approaches and turns along each sail, and another part of it flows in untidy bundles into the slot of the fors'l, speeding up and "streaming" behind the mainsail, curving with the sail and forming smaller bands of turbulance as they flow aft. A third part passes to the lee of the jib and if the sail shape is right bends with it. If not, it breaks up into turbulance. The mean velocity on the lee side of the mainsail then reduces sharply until, at the leach it is equal to that of the flow on the weather side. At this point the wind flow from the weather side and lee side rejoin, and with renewed turbulance they flow away aft, increasing their speed again until, several boat lengths behind, the original average wind speed is regained—this area being the "wind shadow" beloved by racing tacticians.

One impression gained from the tests described is the importance of considering the different character of wind flows, particularly how they are affected by viscosity and its influence on major turbulance and also the possible ranges of energy distribution which may occur.

For the immediate practical aspect, the tests emphasise and help to explain the need for good "escape routes" from sails, to allow the wind to flow with the minimum disturbance or restriction, particularly out of genoas, and from the leeches of mainsails, and of course from spinnakers. This agrees with the known adverse effects of curled leeches, restricted genoa clearances, and inadequate sheeting angles. If high pointing is to be achieved the sail curvature must allow the wind to stream with as little abrupt restriction as possible. We perhaps tend to think of wind only in respect of its velocity. Important as this is from the point of view of the force produced ($f = \frac{1}{2} m V^2$) we should also consider its volume passing any particular point and the effect that major turbulance can have on it. We can imagine and assess the huge volume of wind diverted each minute by say, a big genoa sail which then has to pass through the slot. In spite of the resulting increase in velocity—which is beneficial—too much restriction due to a curled leech or equally to a wrongly cambered mainsail will alter the volume (and mass, m) of wind passing over the whole sail. This can be even more noticeable when a mainsail is squared off too far when running and prevents the wind from sweeping out of the spinnaker. The "cushion" of still air in the spinnaker immediately builds up and the pulling forces from it and from the back of the main are immediately drastically reduced.

These "cushions" or areas of low velocity can exist to a lesser extent in sails in the close hauled position. Obviously the cushions are thinner but nevertheless the wind flow can be seen passing over the outer surfaces of these areas. The inner surfaces are being dragged along with the sails. In this condition the effective sail area will be significantly reduced. The remedy is to keep down the areas of stagnation. An extreme examples of this is the trick of "rolling the wind" out of a spinnaker in light winds (by judicious playing of the sheets). Less noticeable but equally important is the effect of poor escape route referred to above. Again taking a spinnaker as an example (because the effects are so emphasised) the method of encouraging air movement in a spinnaker by forming holes or a slot in the sail has been well tried but with limited success. Our flow tests show that although there is a "leak" out of such a sail it does in fact come from the *back* of the cushion. The front still retains the typical convex shape, though the volume is reduced. Although the leak produces a steadying effect the quantity is not sufficient to release the viscous, turbulent mass of air from out of the sail. There is still much to be learnt from the study of natural wind flow on sails.

THE CALCULATION AND PRESENTATION OF SAILING MEASUREMENTS

BY

J. HOGG,

Parkland Cottage, Curdridge, Southampton.

The principles involved in making sailing measurements in full size yachts has been described in previous A.Y.R.S. Publications (e.g. No. 56) and as the practice of measurement is growing it may be of interest to members who are unfamiliar with these things to consider how the figures obtained by yacht instrumentation can be used to work out the performance and to present it simply and clearly so that it can be studied, discussed and compared with that of other yachts.

The following notes describe two simple methods, one graphical one mathematical, of completing the process and these are followed by a description of the method of presentation—in this case with the use of the Polar diagram, with some comments on the information which can be obtained from the diagram. There are of course other methods of calculation and of presentation but it is thought that if this general method is given first the more specialised versions can follow later.

In describing the two methods a typical example of actual sailing measurements is worked out, by each method.

The main figures obtained from the yacht's instruments are:-
The Apparent wind speed—V_A knots.
The yacht's speed—V_S knots.
Yacht's angle to apparent wind—β (this includes leeway).

From these we require to find:-
The True wind speed—V_T knots.
Yacht's Course to the True wind—γ.
Yacht's Speed Made Good to windward—Vmg knots.

Example

A typical small yacht result might be:
$V_A = 10$. $V_S = 2.6$. $\beta = 34°$.

Method 1. *Graphical*

1. Using a scale of 1 inch = 1 knot draw a vertical line A-B equal to the Apparent wind speed, i.e. 10 inches.
2. With compass at A and radius equal to the yacht's speed (Vs) which in this case is 2.6 inches, draw an arc as shown in Fig. 1.
3. With protractor at A make an angle of 34° for the yacht's course to the apparent wind (β). Draw this line.
4. Through the point C where this line cuts the arc draw a line from B. Then with a set square draw a line at right angles to this from A. Call the line A-D.
5. Measure B-C to find the True Wind. This equals 7.97 knots.
6. Measure the angle at C as shown. This gives γ and equals 44.5°.
7. Measure C-D to get the Vmg. This equals 1.85 knots.

Method 2

Again we are given V_A, V_S and β from the sailing measurements. We require to find V_T, γ and Vmg.

We use V_A, V_S and β to solve three equations which give the required results.

1. $V_T^2 = V_A^2 + V_S^2 - 2\,(V_S \times V_A)\,\text{Cos}\,\beta$

from this V_T is obtained and used in the next equation:

2. $\text{Sin}\,\gamma = \dfrac{\text{Sin}\,\beta}{V_T} \times V_A.$

from this γ is obtained and used to solve the next equation:

3. $\text{Vmg} = V_S \times \text{Cos}\,\gamma.$

Taking the same example as used in the first method:
$V_A = 10$ knots. $V_S = 2.6$ knots. $\beta = 34°$.

Equation 1

$V_T^2 = 10^2 + 2.6^2 - 2\,(2.6 \times 10)\,\text{Cos}\,34.$
From tables Cos 34 is .829.
Then $V_T^2 = 63.65$
$\therefore\ V_T = 7.978$ knots.

Equation 2

$$\text{Sin } \gamma = \frac{.5592}{7.978} \times 10.$$

From tables Sin 34 = .5592.

$\therefore \quad \gamma = 44.5°$.

Equation 3

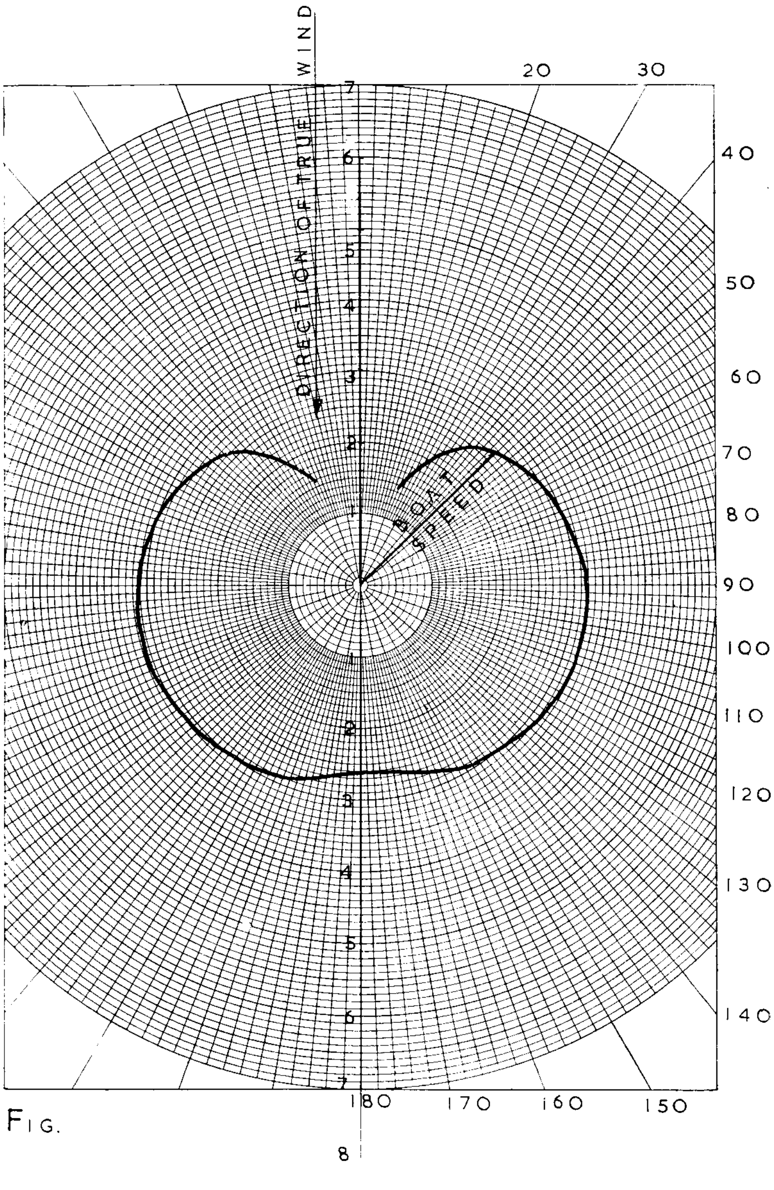
$$\text{Vmg} = 2.6 \times \text{Cos } 44.5$$

From tables Cos 44.5 = .7153.

$\therefore$ Vmg = 1.85 knots.

Presentation of Results. Polar Diagram

The use of Polar Diagrams for presenting the Yacht's performance can take several forms. Basically the diagram shows the speed of the Yacht through the water when sailing at various angles to a particular (True) wind. For example in the case shown above, the True wind was 8. kn. (approx.) and when sailing at 44.5° to it, the yacht's speed was 2.6 kn. This speed will of course vary as one sails fuller or closer to this wind, as a series of test runs will show. When a number of runs have been made and the speeds noted (covering the close hauled sector, through reaching, to running) the speeds can be plotted on the circular Polar chart (suitable graph paper can be obtained). When these plots are joined the characteristic polar curve is formed. Curves representing results in other wind speeds will lie within or outside this curve and their comparative shapes give indications of the yacht's behaviour in different wind speeds and what her particular capabilities are. Fig. 1 shows a number of points joined up to form a polar curve. The shape of these curves can alter significantly, particularly in the down wind sectors in different wind speeds. It is hoped to go more fully into the implications of these important changes on another occasion and to refer to non dimensional scales. For the present we might examine the curve shown and follow it round from the close hauled position to the "dead run" at 180° to the True wind. Beginning at the head-to wind position where Vs is virtually zero the yacht starts to turn into the very close ("pinching") sector. As γ is increased, i.e. as she is sailed successively freer her speed increases and also her speed made good to windward (Vmg). The latter reaches optimum at $\gamma = 40°$ after which it reduces until at $\gamma = 90°$ it is zero (at the "reaching" position). It will be seen that the example we took for the calculations was not the optimum Vmg for this wind speed. Although γ was only $4\frac{1}{2}°$ freer it had a significant effect on the Vmg, which illustrates the critical nature of this "knuckle" in the windward part of the curve, on which the helmsman must balance to attain the optimum


DIRECTION OF TRUE WIND
BOAT SPEED
20
30
40
50
60
70
80
90
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110
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170
180
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2
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6
7
8
FIG.

POLAR CURVE

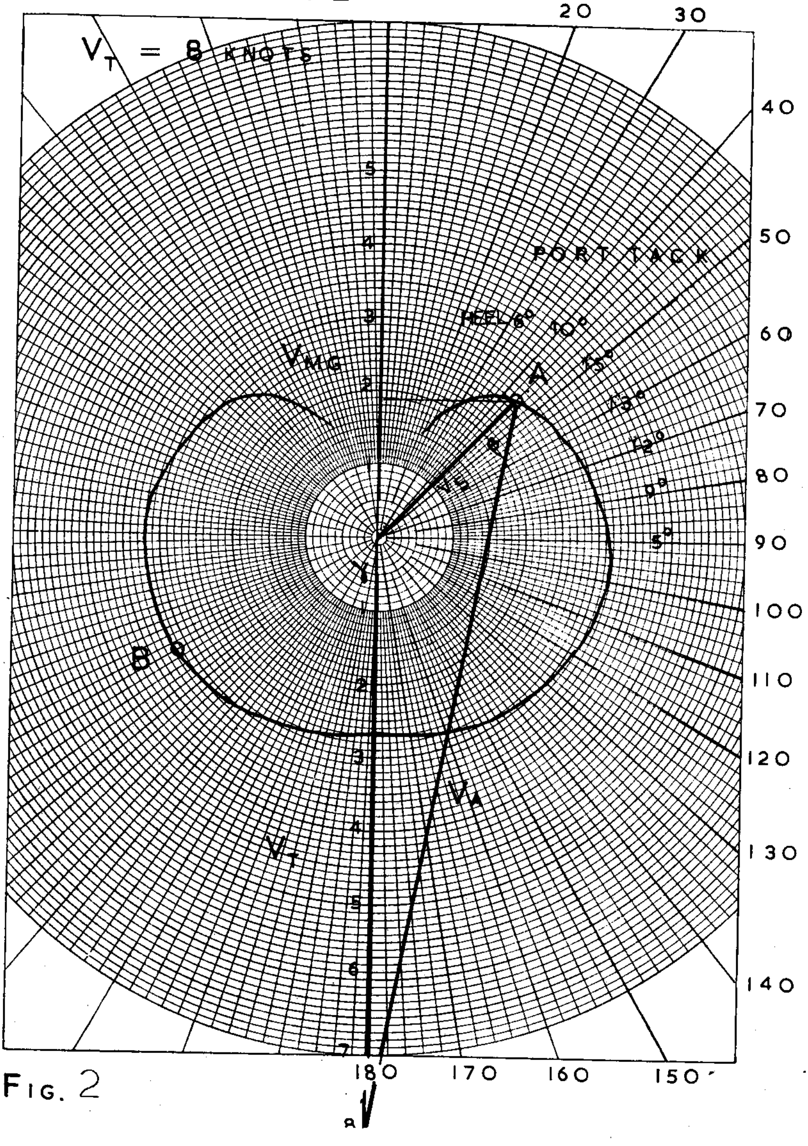


FIG. 2

Vmg. Continuing along the Polar curve, after $\gamma = 90°$ the speed made good becomes negative, that is Speed made good *from* windward. At about the 110° sector there begins another "knuckle" (quite a pronounced one in light winds) where decisions have to be made to carry Shy spinnakers, and whether down wind tacking will pay. From this point onwards the apparent wind becomes increasingly less than the true wind until, at $\gamma = 180°$ the yacht's speed is wholly deducted from the true wind speed and the apparent wind is only equal to the true wind minus the yacht's speed, and in some conditions can fall almost to zero.

Considering the windward sector again it can be seen that the example chosen above has been indicated on the curve by joining the centre to the point on the curve so that $\gamma = 44.5°$. Vs of course equals 2.6. Now by putting the True wind value on the vertical scale one sees that the familiar Vector triangle can be joined up (although inverted). This produces a most useful means of deducing information from any given Polar curve. Thus by selecting *any* point on the curve and joining up this to the true wind (which is always stated for any given curve) all the necessary information of sailing conditions at this point can be directly measured with a pair of dividers, using the same scale as the polar. The values for β, VA and Vmg are therefore available. Fig. 2 shows the analysis of two such points on this curve. Point "A" on port tack with $\gamma = 44.5$ and "B" at $\gamma = 120°$ on starboard. The triangle for point "B" has not been drawn in so as to avoid confusion, but the values shown were obtained by measurements from the curve, as described.

Another important set of values can be related to any particular polar curve. These are the yacht's heeling angles. These are best shown at individual points on the curve. Fig. 2 shows some typical values of θ for this wind speed, the angles being measured at the same time as the other performance figures. The aim with polar curve presentation should, I suggest, be to show only such information as is necessary to arrive at the sailing conditions at each point by the methods indicated above, and so avoid masking the picture with too much detail.

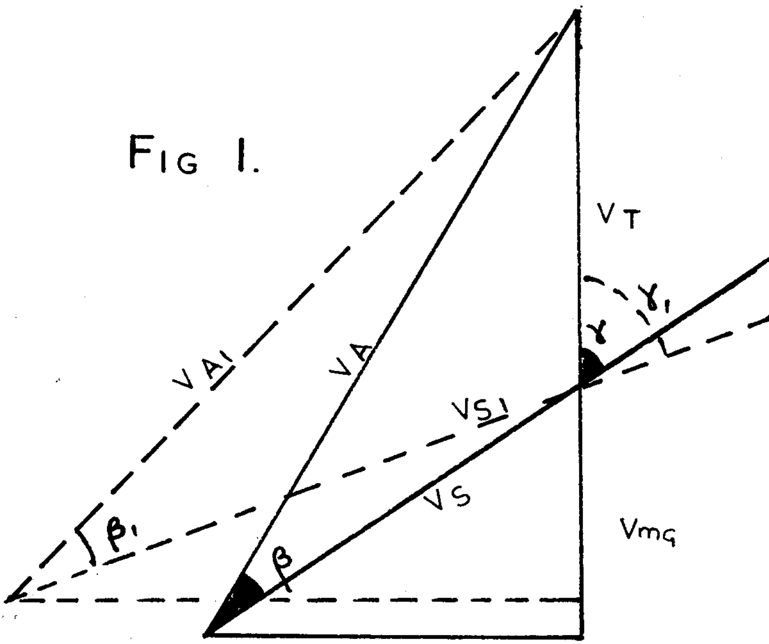
Values from Fig. 2

	Point A	Point B
VT	8	8
VA	10	6.9
Vs	2.6	3.2
Vmg	1.85	−1.6
γ	44.5°	120°
β	34°	97.5°

VANE GEAR AND MULTIHULLS

Dear John,

Jock Burrough has referred to the conditions when a Vane steered multihull occasionally will not differentiate between different courses on the wind, due to the large increase in boat's speed as the course angles increase, bringing the apparent wind forward, so that its angle remains almost constant.



Defining this:

- V_T is taken to be constant.
- γ increases to γ_1.
- β remains constant, therefore the vane notices no change.
- V_A increases to V_{A_1}.
- V_S increases to V_{S_1}.

The result is a breakaway. Considering methods of correcting this tendency, whilst still retaining the vane steering:

Using the change in apparent wind speed V_A

It has been suggested that use could be made of the wind's tendency to veer when gusting. I have measured wind speed and angle simultaneously but one finds that the gust/veer conditions are not consistant. In S.W. winds this is particularly so. The North westerlies conform better but I would not say above 50% of the gusts behave in this way.

However an asymmetric vane would sense an increase in VA and might be used to correct the breakaway, without upsetting the normal vane action. Fig. 2.

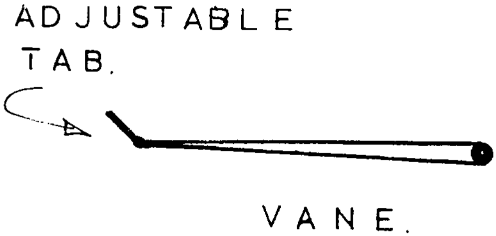


FIG 2

Using the change in Yacht's speed Vs

1. The sudden change in Vs would provide a useful control signal, acting say on a small water drogue attached to an arm on the vane to provide a luffing action when Vs increases. Fig. 2A.

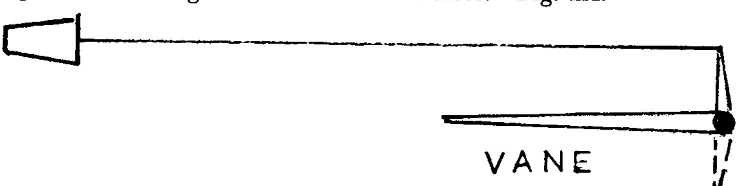
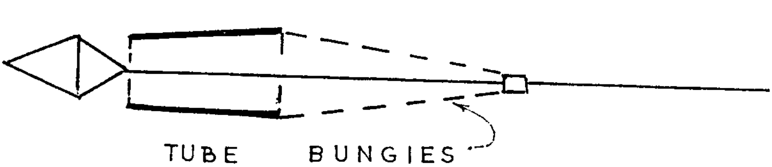


FIG 2A

2. Alternatively a larger water drogue, attached to the hull, and designed with a non linear response, (i.e. its drag increases suddenly with speed) would provide a strong breaking action if Vs increased above a selected value. At speeds below this, the drogue would offer little resistance. Fig. 2B shows the principle.

FIG 2B



Other Methods

Here I would ask for Jock Burrough's views because I suggest that under breakaway conditions there will be an increase in heeling angle θ even if only by a relatively small amount. If so this would provide a very rapid and easily sensed signal. As I suggested at the meeting, the correction could be applied to the vane by adjusting the counterbalance weight to suit the prevailing conditions. Also this could be used in other conditions, for example when reaching and as a safeguard against overheeling. The θ/V_A response time is very rapid—much quicker than the V_S/V_A response.

I think that this is a most interesting problem and well worth some more thought.

JOHN HOGG,
Parklands Cottage, Curdridge, Hampshire. 14 March, 1967.

DIMENSIONLESS RATIOS

BY

JOHN F. DARBY
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The speed, V, of a boat is always related to the square root of its waterline length, l, because the condition for dynamical similarity between the motions of different size bodies of similar shape under forces depending on gravity, such as the wave-making resistance of ships, is constancy of the ratio $V/l^{\frac{1}{2}}$. In that form the ratio has physical dimensions in length and time, that is, its value depends on the units used, and it is better expressed as the Froude number $F = V/(gl)^{\frac{1}{2}}$ where g is the acceleration of gravity. This expression is dimensionless, therefore independent of size, and has the same value whatever consistent set of units is used for V, l, g. The value of 1.4 is usually given for the ratio $V/l^{\frac{1}{2}}$ for beamy displacement hulls at full speed, which requires the units to be stated—here speed in knots and length in feet—becomes $F = 0.42$ in non-dimensional form.

Two other ratios are important to fast boats that may plane if they are light enough and driven hard enough. The first is a criterion for lightness, usually the ratio of displacement to the cube of the length; most writers take the displacement in tons, the length in feet and multiply the result by 10^6 to bring it to a convenient size. The units are then microtons per cubic foot or tons per cubic hectofoot, but a dimensionless form is preferable and easily found. If the displacement is divided by the density of water we have the volume of water displaced instead of the mass, and the ratio of this volume to the cube of the length is dimensionless and independent of the units used, provided only that they form a consistent set. Alternatively, comparing the cube root of the displaced volume to the length results in a convenient magnitude with no need for the arbitrary factor of a million. For examples—a 14 foot International displacing 600 lbs. of sea water of density 64 lbs. per cubic foot gives a ratio of .151; a Lodestar 31 feet on the waterline gives .133 when displacing 4500 lbs. empty and .151 when loaded to 6500 lbs.; Vagabond 1 of 33.25 feet gave .102 when specially lightened to 2500 lbs. for trials of speed and stability and the hypothetical C-class Catamaran in A.Y.R.S. 46 displacing 900 lbs. on a length of 22 feet gives .110.

The other important ratio relates power to weight. Here, some writers err by dividing the sail area by the two-thirds power of the displacement. It is true that the displacement is proportional to a volume and hence that the two-thirds power is proportional to an area, so that the ratio chosen compares similar things, but they are not the right ones. A ratio of driving force to inertia is required; the driving force is found by taking the product of the sail area, S, and a pressure, P—standard atmospheric pressure does very well—and the inertia is the mass M. If the product SP is in absolute units then comparing it with the weight Mg gives a dimensionless quotient; alternatively SP may be taken in gravitational units and the mass similarly to give the same result. If the pressure is left out, a dimensioned ratio results and the units have to be given, usually square feet per ton. It then corresponds to the dimensioned speed-length and displacement-length ratios mentioned above.

The difference between the two can be illustrated by an example. Suppose a heavy crew brings the total weight of a Flying Dutchman to 700 lbs. for her 190 sq. ft. of sail and a light single-hander in an International canoe causes an all-up weight of 350 lbs. for 106 sq. ft. The comparison is:

	S/D	$S/D^{2/3}$
F.D.	608 sq. ft/ton	412 sq. ft/ton$^{2/3}$
Canoe	678 sq. ft/ton	363 sq. ft/ton$^{2/3}$

The differences are in each case about 10 per cent but in opposite directions! If we multiply the first column by 1 atmosphere of pressure = .945 tons per sq. ft., the dimensionless results are 575 and 642. Corresponding quantities for the craft mentioned earlier are 14-footer 488, Lodestar 181 and 125, Vagabond 440, and Catamaran 472 with 200 sq. ft. of sail and 707 with 300 sq. ft.

DESIGNING FOR SPEED TO WINDWARD

BY

EDMOND BRUCE

Lewis Cove, Hance Road, Fair Haven, N.J., U.S.A.

Situation:

Is the reader one of those sailors who feels quite satisfied when his leeway angle, or sideways drift, is very small, even when sailing hard on the wind? It is the writer's contention that this small leeway may be an indication of a poor hull design. It suggests too much lateral place and therefore too much wetted surface.

Several syndicates, involved with "America Cup" contenders, have worried about the conflicting facts that:

a. At full size, only about one to one and one-half degrees of leeway is experienced to windward.
b. Towing tank data, on a precision model of the boat, had shown leeway angles of four to five degrees, on high-pointing, windward courses.

These people tend to blame these discrepancies on the towing tank and to an assumed inaccuracy in scaling a model to full size.

The writer does not believe that the towing tank proper or scaling is at fault. The difficulty may lie jointly in the test methods decided upon and in the magnitude and angle of sail force represented by the so-called "Gimcrack Coefficients."

This writing will try to delve into this situation and present the author's viewpoint. A better understanding will help all sailing. If faults do exist, some cures are suggested.

Significance of Leeway Angle:

Our concern for the value of the full size hull's leeway angle can be explained by the following sequence of related logical statements:

a. The leeway angle of a hull is identical with the angle of attack of a symmetrical foil, as used in studies of fluid dynamics.
b. There exists an angle of attack which produces an optimum lift-drag ratio for a foil or hull.
c. A highest lift-drag ratio corresponds to a smallest drag angle in the "Course Theorem." (See A.Y.R.S. No. 37, page 17 and No. 41, page 25).
d. The smallest drag angles, for hull and sail, result in the smallest course angle to the apparent wind since the latter is always their sum.
e. Therefore, a hull leeway angle exists which will produce the highest pointing of the hull's course in respect to the direction from which the apparent wind is blowing.

One must comment on the above, also on the "Course Theorem," and say that all of these pertain to angles alone and do not include force or velocity magnitudes. These absent magnitudes will be provided from empirical data, on sail and hull, later on in this writing.

If speed is the primary objective, a competent designer should adjust the size of his chosen under-water body so that a maximum, lateral, lift-drag ratio, at the hull's speed, is achieved to counteract the sail force that is expected. The latter is limited by stability considerations. If the water resistance were sqaure law with speed, as is the case for the sail, also in aeronautics, the best lateral area and angle of attack would be constant at all speeds. Since this is not entirely true for a hull, due to wave-making, a fixed keel must be a compromise. This gives the adjustable area of a centerboard some advantage when properly used. When the area of a keel is constant, a small change in leeway angle must be expected with changing speed or with a change in course.

It has been the writer's towing-tank and full size experience that every hull, in which the lateral area has been adjusted to achieve the optimum lift-drag ratio to windward, the leeway angle has never been less than four-degrees or greater than six-degrees. It would appear that any hull outside of these limits probably is of improper design.

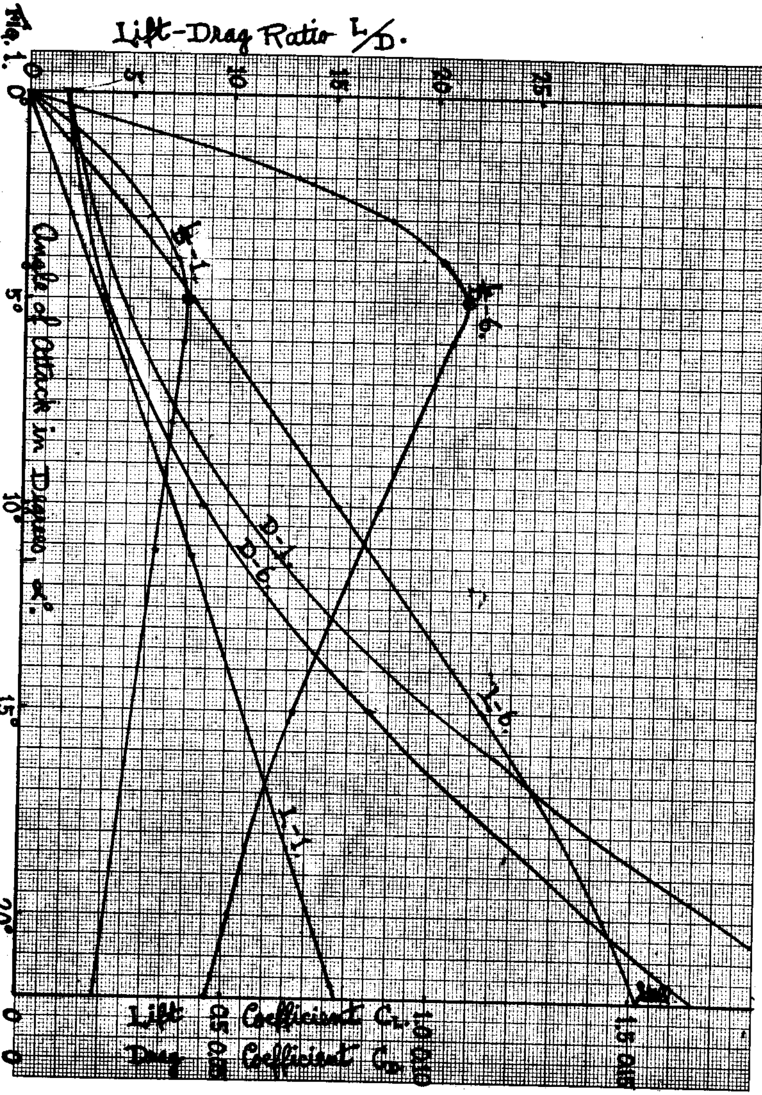
Many keel boats have areas which are too large. Quite a few multi-hulls have boards that are too small with excessive leeway as the result. Let us examine the literature of aeronautics and see if we can confirm the conclusions as to the best angular range.

The fixed keel, of say a 12-Meter, is subject to the same physical laws as a foil in aerodynamics after a proper allowance for fluid density is made. However, a strict requirement is that the keel must be deep enough not to contribute appreciably to surface wave-making.

In Fig. 1, examine the curves of the lift and drag coefficients versus angle of attack for two N.A.C.A. No. 0012 foils of aspect ratios 6 and 1.

The latter corresponds broadly to many keels in sailing craft. These are further handicapped in lift-drag ratio due to the drag of the hull proper. In this foil-shape designation, the first 00 indicates a symmetrical foil. The final 12 means a thickness which is 12 per cent of the cross-sectional chord length. This thickness is among the best for airplane symmetrical foils, at least at the high Reynold's Numbers used. At the low Reynold's Numbers, encountered in sailing, further investigation is badly needed, due to "separation."

Also plotted in Fig. 1 is the ratio of lift to drag for each of these two foils, which differ only in aspect ratio, as stated. It is seen, in each case, that optimum lift-drag is achieved at an angle of attack of about



5-degrees. Even though the low aspect ratio foil is much poorer, its angle of attack for highest L/D is substantially the same. Thus one might conclude that aspect ratio does not appreciably affect the optimum angle of attack for a given cross-sectional shape of a foil.

As to varying thicknesses of foils, Table I indicates the angle of attack at which the stated optimum L/D was achieved, in N.A.C.A.

TABLE I.

Aspect Ratio = 6 in all cases. At high Reynold's Numbers.

Foil	Max. L/D	Angle of Attack Degrees	C_L	Max. C_L	Angle of Attack Degrees
Flat Plate	6.7	5	0.40	0.78	15
NACA #0006	23.5	4	0.40	0.88	16
#0009	22.5	5	0.40	1.27	18
* #0012	21.6	5	0.40	1.52	22
#0015	21.0	5	0.40	1.53	22
#0018	19.8	6	0.40	1.50	23
#0021	18.5	6	0.40	1.38	23
#0025	16.5	6	0.40	1.20	23

* Best overall for airplanes due to high lift and high L/D.

reports, for symmetrical foils. All optimum angles are within the cited range of 4 to 6 degrees. Also note the remarkable fact that, at the fixed aspect ratio but regardless of maximum lift, the coefficient of lift is always 0.40 at the angle where maximum lift-drag ratio is achieved.

Returning again to Fig. 1, it teaches that, at the angle of attack of 22 degrees which produces a maximum lift coefficient of 1.52 for the aspect ratio of 6, the resulting lift-drag ratio is only 9 as compared to 21.6 at an angle of 5 degrees. It follows that for highest pointing, one does not necessarily select a shape that gives the maximum lift. The thinner foil N.A.C.A. No. 0006 of Table I would seem slightly better at L/D = 23.5 and C_L = 0.40 than No. 0012 even though its maximum C_L is much smaller.

High lift devices, such as airplane take-off flaps, are of little value in a keel, except for steering, because of the high resulting drag. The author disagrees with those that advocate a slight weather helm rather than a centered helm with a balanced sail position. The keel curvature achieved with the angled rudder is too far aft. It resembles a flap. A sail balance that achieves some degree of weather helm is one of the factors which cause a reduction in leeway angle, possibly one degree or more. A centered helm, on a properly balanced boat, still has some side pressure due to the keel's angle of attack.

The writer undertook a simplified mathematical analysis so as to try to understand why an optimum angle of attack in the range of 4 to 6 degrees is so persistent. I do not wish to burden this writing with mathematical details that would be of interest to so few readers.

However, for those who may want to investigate for themselves, the final result is stated in the following:

For a flat plate, if C_P is the normal pressure force coefficient and C_F is the tangential frictional force coefficient, also if α is the angle of attack, L/D maximum works out to occur when:

$$\frac{C_P}{C_F} = \frac{1}{\tan^2\alpha}$$

Now if $C_P = 1.25$ (a reasonable value for both sides combined) and $C_F = 0.006$ (twice the Schoenherr coefficient since both sides are involved), the calculated optimum angle of attack turns out to be about 4 degrees which is quite independent of size and shape. The ratio of $\frac{C_P}{C_F}$ would have to change by more than 50 per cent to alter this optimum angle of attack only one degree.

One might conclude that the range of 4 to 6 degrees, as the optimum angle of attack, is so persistent because only the fundamental ratio of forces, with a flow normal to or tangential to an elementary surface, is involved. These may be quite rigidly fixed quantities in nature. Using the overall performance measuring instruments, which the writer described in A.Y.R.S. No. 56, it was found on a 38-foot keel-centerboard ocean racer, that even on a reach, the centerboard area had to be reduced, for best performance, so that the leeway angle was again between 4 and 5 degrees. This is reasonable since one always wishes to provide the required lateral lift with the least possible drag. In other words, the best possible lift-drag ratio is still required even though the total amount of lateral lift desired was reduced by providing a smaller area. In a boat having a fixed keel area, the leeway on a reach is bound to be less than when hard on the wind. This means that an excess of drag is unavoidable.

From all the above, it is seen that there is a substantial case for being suspicious of a hull design where the leeway angle is out of the range of from 4 to 6 degrees. Some people apparently considered the writer very irreverent when he stated, in print, that in his opinion, the "America Cup" contest was being conducted in "house-boats." The 12-Meter class members seem to have copied each other's mistakes in lateral plane. I would like to predict that, if a proper leeway angle is included in an otherwise good design, a winner will be produced, if properly handled.

I will now attempt to show that one villain in the situation may be the magnitude of the "Gimcrack Coefficients." Too large a coefficient used in towing tank tests would result in too small a leeway angle at full size, as we will see later. I believe that the lateral plane areas, often used in 12-Meter boats, should be reduced at least one-third. This correction together with a reduction in weather helm could provide a leeway angle of some 4 degrees.

Gimcrack Coefficients:

At some towing tanks, sailing hulls are tested for windward performance using assumed component magnitudes and their determining direction for the sail forces. These sail forces are represented by coefficients obtained from tests which were made while sailing the approximately 6-meter yacht "*GIMCRACK*" on the wind with the main-sail luff just "full and by." Since these coefficients are independent of sail area (or apparent wind strength) this area can be adjusted to suit the stability of the hull being tested or to some restricting sail area measurement rule.

A danger that must not be overlooked is that, if by chance, the *GIMCRACK* coefficients were too large and the hull's lateral plane area was adjusted to accommodate them, real sails on the final full size boat, with a rule-prescribed sail area, would be teamed with a hull lateral plane size that is too large to achieve an optimum lift-drag ratio.

Let us look into the history of the *GIMCRACK* Coefficients and come to some conclusion as to their accuracy. Thirty-three years ago, there appeared some suggestions which made possible a considerable advance, for that day, in the technical understanding of sailing. Among other things, there were proposed the so-called "Gimcrack Coefficients." These permitted the extension of towing tank sailing hull work, beyond merely running courses, to include those of windward sailing.

For steady state equilibrium, a sailing hull always automatically adjusts its three component angular attitudes and speed so that the water caused resistance exactly opposes the direction of the sail force but equals its magnitude. From the time of the Gimcrack proposal to the present, it has been the usual practice of some commercial towing tanks, when dealing with simulated windward sailing, to assume that the hull is driven by a Gimcrack type of sail plan. By using only one standard sail plan, it was felt that the merits of various hull designs could be more accurately compared.

In the original publication, Stevens E.T.T. No. 10, its author revealed some weaknesses in the Gimcrack full size tests. The anemometer was reported as hand-held by a man on deck, not at the higher center of effort of the sails. Due to the velocity gradient of the wind with height above water, such readings were undoubtedly lower than those at the height of the center of effort of the combined sail plan. The total coefficient of the lift and drag component coefficients, that were used, times the sail area times the *square* of the correct apparent wind velocity must equal and oppose a fixed equivalent water force, as was determined from the displacement's righting moment for the angle of heel and the forward resistance of the hull when towed. For a given force, too large a coefficient would result from a wind velocity that was too small, especially since the wind velocity must be squared.

If the original total coefficient, which included the fluid density, were converted to the familiar aeronautical type of coefficient, which expresses density separately, its magnitude would have been 2.34, a ridiculously high value compared with known foils. The author was aware of this discrepancy and worried about it. He compared his value with those obtained by E. P. Warner who used 18-inch by 3-inch rectangular, rigid, curved metal plates in wind-tunnel tests. Warner's maximum total coefficient was reported as 1.85.

In Stevens report E.T.T. No. 16, the author arbitrarily reduced the total coefficient to 1.835 based on a published wind velocity gradient with height, as was mentioned previously. This was no more than an educated guess since the hull's effect was not considered. The writer feels that this value is still too high. A rigid curved plate, having an aspect ratio of 6, would have a big advantage over soft cloth sails which were subject to luffing, subject to the presence of parasitic windage and having lower aspect ratios.

The coefficients employed should have been still further reduced. When sailing hard on the wind, one should trim sails for a maximum lift-drag ratio. The coefficient for this adjustment is smaller than the maximum coefficient. For example, Table I indicates that Foil No. 0012 at an aspect ratio of 6 and having maximum Cs at 1.52 should use Cs at only 0.40 for a maximum lift-drag ratio of 21.6. Later, in Table II, it will be seen that a single cloth sail on a dinghy, in the presence of parasitic windage, employs Cs at 1.39 compared with a maximum of 1.61 to obtain a maximum lift-drag of only 3.27 or a drag angle of 17 degrees.

Thus the better the sail or foil, the smaller is Cs to achieve an optimum lift-drag ratio. The poorer sail has to use higher values to overcome excess drag. The writer would be better satisfied if Cs maximum for the Gimcrack Coefficients were about 1.6. Also the Cs, used for highest pointing or maximum L/D, might be about 0.9 when used for towing tank work to windward. These were values measured by the writer using tethered tests on 600 square feet of mainsail and jib. A leeway angle of 4 degrees was achieved with these sails on a 38-foot craft when the keel's centerboard was carefully adjusted.

There are further treatments of the Gimcrack Coefficients in Stevens E.T.T. No. 17 and No. 22 but the non-heeled value of the total coefficient for windward sailing was not changed from the 1.835 value to my knowledge.

The writer has some additional complaints about the determination of the Gimcrack Coefficients:

a. The course to the apparent wind was never actually measured. This is a sensitive parameter when on the wind.
b. No consideration was given to the harmful windage on the hull and rigging which certainly would affect the coefficients.
c. The stated average angle of attack for the sails of 2 degrees seems extremely low. This is hardly possible without luffing.
d. There is no proof whatever that the fixed sail coefficients, as reported, achieved the *best* speed made good to windward. Only a single course was employed.

In view of the costs in time and money of the many tank tests that have taken place, more accurate coefficients are certainly warranted. I have little quarrel with the excellent running tests that the towing tanks have produced. However, I have understandable doubts in the "speed made good" reports that are based on the Gimcrack Coefficients. Many boats can improve their speed directly into the wind by sailing freer. This is especially true of multi-hulls which might fare badly under the Gimcrack procedure's predictions.

I am glad to report that various people recognise the need for more accurate coefficients and are taking steps to produce them. The writer has a number of suggestions which are described in the section that follows:

Suggested Replacement for the Gimcrack Coefficients

Any new effort to determine sail force coefficients should be improved in method and made more encompassing than the Gimcrack Coefficients. For example, all courses should be included, not just one hard on the wind. The optimum angle of attack for the sails should be specified for any course. This would include the highest pointing course of which a hull is capable or, in other words, the hull's smallest possible drag angle without "stalling." For highest pointing, no one sail adjustment suffices for all hulls. The same holds true for the best "speed made good" to windward and the course it requires.

In all that follows, we must thoroughly understand the "Course Theorem," as previously mentioned, and what is meant by a sail or a hull drag angle. It is this new theorem that has made possible a better and simpler understanding of technical sailing. A hull drag angle, geometrically, is the angle between the direction of the total sail force or the hull resistance and an abeam perpendicular to the hull's course, not to the heading. A sail drag angle is the angle between the same total sail force and a perpendicular to the direction of the apparent wind. The course angle to the apparent wind can be proved to be the sum of the sail and hull drag angles as will be seen later in Fig. 2. This produces the exact angular opposition required between the sail force and hull resistance.

Sails can be compared, at any sail drag angle, based on only their own coefficients. These sail coefficients can be obtained, for all sail drag angles and quite independent of wind speed, from wind-tunnel tests or from full-size tethered tests which the sailing amateur can perform. For accuracy, a procedure must be provided which takes account of the parasitic windage on hull and rigging. The full-size tethered type of sail test produces such results without extra effort.

The Gimcrack Coefficients compare hulls, on one windward course only, by assuming that they use one standard type of sail plan and adjustment. Various hulls can be compared more simply by examining only their own coefficients, for all given hull drag angles and hull speeds but independent of a sail's drag angle. Data then would be available for a hull on all courses and any sail plan, not simply running and hard on the wind with a Gimcrack type of sail, as at present.

The towing tank should be equipped for hull total force measurements versus any hull drag angle and speed within range. The towing force, at a known angle to the course, should be applied through a point equivalent to the sail's centre of effort. The model hull should have no angular attitude restraints whatever. This is particularly true in waves or when any degree of "snaking" is present due to the stern vortices which so often occur. The hull will self-adjust its own angular attitudes of heel, pitch and yaw.

A method should be available for combining both the sail and the hull coefficients to predict overall performance on any course, over a range of wind strengths. The speed data could be plotted in polar diagrams of course in respect to both the true and the apparent winds.

A simple graphical method for obtaining the *optimum* speed made good to windward is possible, not merely a speed made good on a single course as in the Gimcrack method. This best speed made good to windward requires an optimum adjustment of sail angle and hull course as will be described later.

All of the above recommendations are accomplished in the following suggested procedure:

Fig. 2 shows the aeronautical type of equation and plotted sail data obtained from tethered tests on a full-size International 12-foot Dinghy. This is a polar curve of the sail total coefficient Cs versus the angle between its force direction, O-Cs, and the direction of the apparent wind source, O-A. Note that this angle is always greater than 90 degrees. The sail's angles of attack are marked along the curve.

Also shown is the corresponding drag angle for the sail, δ_S. It is the angle between the force direction O-Cs and O-Y, a perpendicular to the apparent wind direction. By definition, the tangent of this angle equals the sail coefficient drag component CSD over the sail coefficient lift component CSL or Ds/Ls.

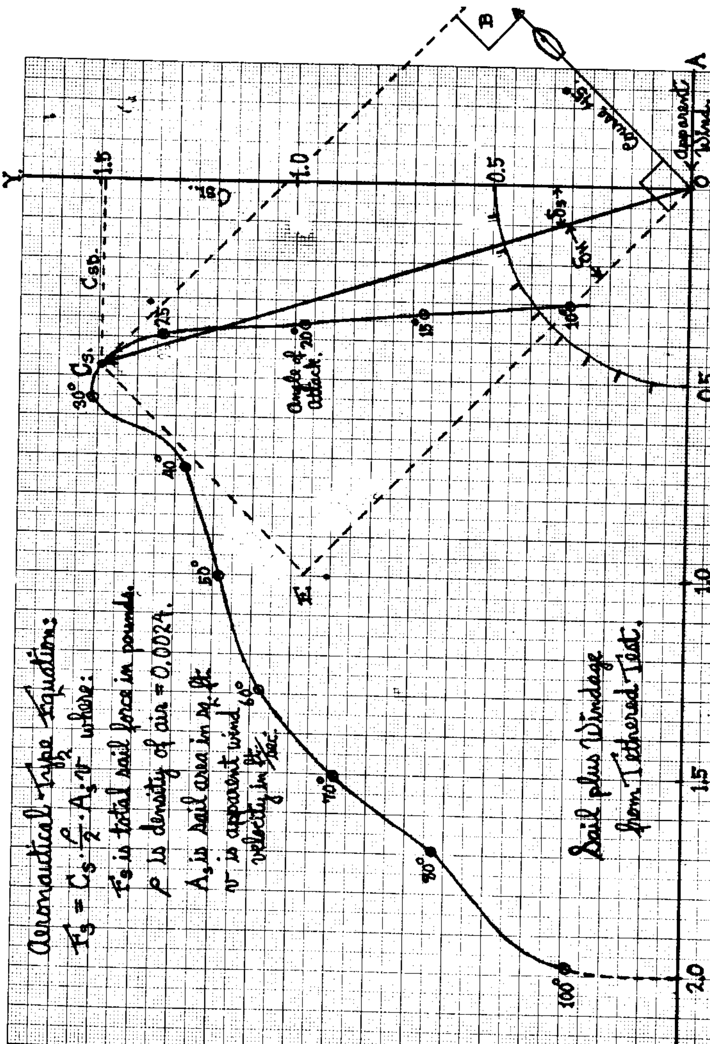


FIG. 2. Polar Plot of Total Sail Coefficient Cs for International 12-ft. Dinghy.

Cs is an aeronautical type of coefficient to enable comparison with known aircraft data. Also, the above mentioned tethered type of sail testing was described starting on page 23 in A.Y.R.S. No. 40. Improved directional stability can be obtained with a Y-shaped bridle attached to bow, stern and mooring.

Fig. 2 shows a graphical method for the determination of optimum sail values Cs, CSD, CSL, δs and α for any given course of the hull in respect to the apparent wind. As an example, there is drawn a boat's course assumed as being 45 degrees from the apparent wind.

The best values of Cs and angle of attack of the sail, for any course, is that which produces the largest component of sail force in the direction of the hull's travel. This optimum driving component O-B can be obtained graphically by means of the dotted line, B-Cs which is simultaneously perpendicular to the course and tangent to the curve of coefficients. The point of tangency, Cs, determines the magnitude of all the above desired values.

From the "Course Theorem," we know that the course angle must equal δs + δH. From a graphical construction, the sail drag angle δs has been determined. Obviously, the required drag angle for the hull, δH, can be obtained by subtraction. It can be represented also by a graphical construction as follows:

In Fig. 2, the dotted line O-E is drawn perpendicular to the boat's course O-B. As previously described, the angle δH, between this line and the sail force direction O-Cs, is the required hull drag angle.

Adding the indicated drag angles δs and δH, in Fig. 2, gives a graph angle equal to the drawn course angle to the apparent wind. This can be proved by the fact that the enclosing lines of these summed adjacent angles are respectively perpendicular to the apparent wind line and the boat's course line, therefore their included angles are equal. Thus the "Course Theorem" is proved.

Precisely as was done for the course angle of 45 degrees, in Fig. 2, the precedure was repeated for a range of all possible course angles from 36 to 180 degrees. The results are listed in Table II together with certain comments. There is added, in that table, the sail's best adjustment if it were on an ice-boat, rather than on a water-craft. This demonstrates that a sail must be adjusted depending on the hull for highest pointing. A fixed adjustment, as used in the Gimcrack procedure, seems in error.

The contents of Table II are plotted in Fig. 3. Here are expressed all of the sail's optimum parameters and the drag angle that is required of the hull for any course.

TABLE II.

International 12-foot Dinghy *Sail* including Hull Windage.

Comments:	Course to App. Wind $\delta_S° + \delta_H°$.	Sail Drag Angle $\delta_S°$.	Reqd. Hull Drag Angle $\delta_H°$	Sail Angle of Attack $\alpha°$.	Equiv. Aeronautical Total Sail Coeff. Cs. Cs.
An Ice-Boat Adjustment	17° Smallest Possible	17° Smallest Possible	0°	25°	1.39
Highest Course & Best Speed Made Good to Windward	36°	18°	18° Smallest Possible	28°	1.51
	45°	19°	26°	29°	1.56
	60°	21°	39°	30°	1.61
	90°	21°	69°	30°	1.61
	120°	21°	99°	30°	1.61
Sail Stalled	150°	75°	75°	85°	1.90
Sail Stalled	180°	90°	90°	90°	2.00 (Windage adds).

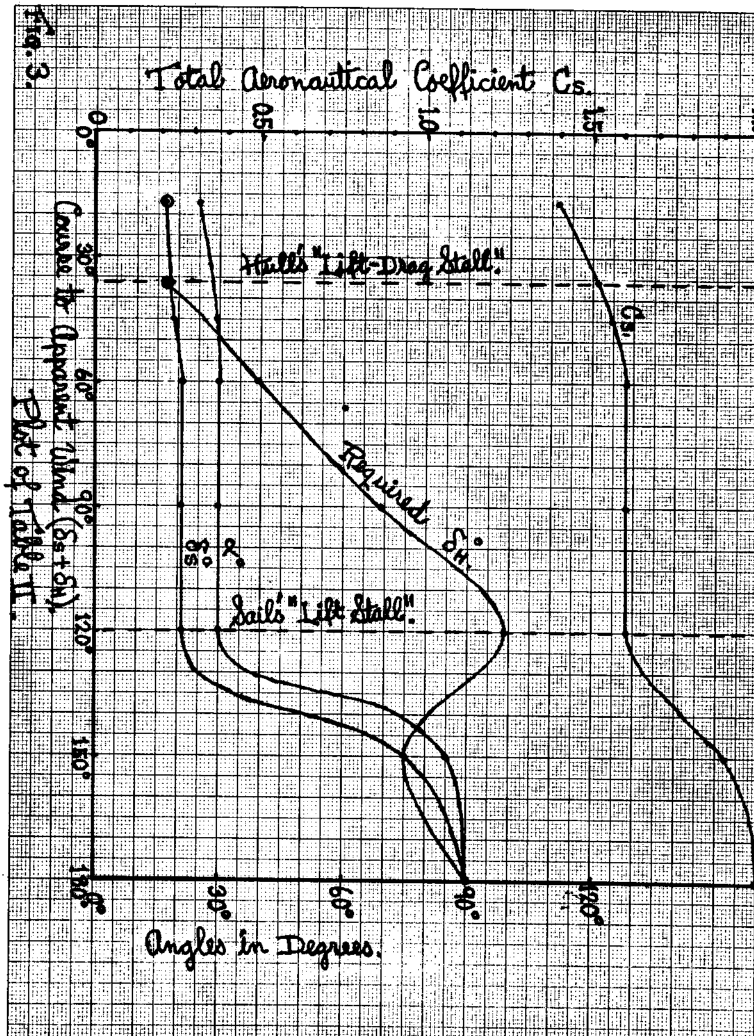
Above plotted on Fig. 3.

In the design of a towing tank, the writer prefers towing the model with a cord and falling weight rather than by an overhead carriage on rails. A falling weight privides a constant force whereas the carriage achieves a constant speed. Constant force permits studies of acceleration and other non-steady-state phenomena such as hull "snaking" and motion in waves.

A falling weight system can easily produce a towing force through a location equivalent to the center of effort of the sails. Important is the fact that the force can be at any horizontal angle to the hull's course. The hull seeks its required attitudes of heel, pitch and yaw automatically. There is no tiresome "fooling around." Possibly a carriage system can be modified to do many of these things also.

Fig. 4 shows the hull coefficient K_H versus towing angle δ_H plotted for two chosen speed-length ratios. Note that changes are not great with varying speed. There would be no appreciable difference if it were not for wave-making. As the towing angle is measured from a horizontal perpendicular to the course, it becomes equal to the hull drag angle, δ_H. The required hull drag angle for each course, for the dinghy being measured, is obtained from a curve shown in Fig. 3.

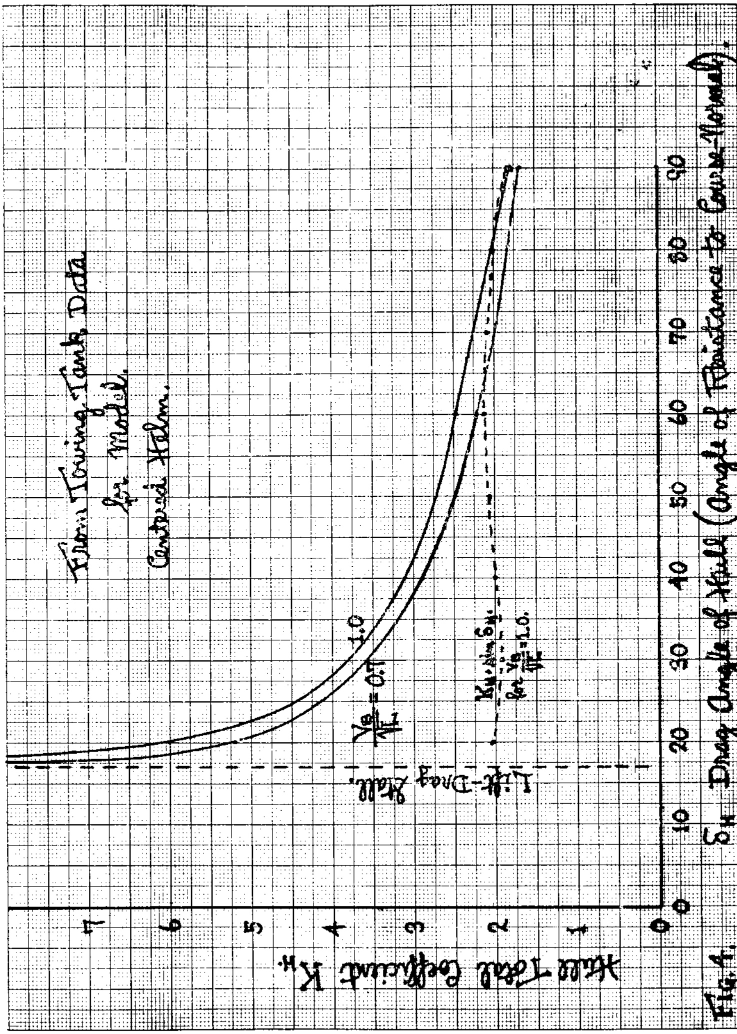
Whereas an aeronautical type of coefficient Cs was used for the sail, to enable comparison with aeronautical data, a hull coefficient of this type would be more complicated than need be. It is difficult to accurately measure wetted surface area due to wave-making which varies with each speed. For this reason, a simpler type of hull coefficient is used. It is in terms of the hull weight W in pounds rather than wetted area. Also, the total resistance R_T is in pounds and the



boat velocity V_B is in knots. This new coefficient will be called K_H rather than C_H because of these differences. It has been derived in other writings (A.Y.R.S. No. 36 page 60) as being:

$$\frac{R_T}{W}\,\% = K_H \,.\, \frac{V_B^2}{W^{1/3}}.$$

$$\text{Thus, } K_H = \frac{100\,.\,R_T}{W^{2/3}\,.\,V_B^2} \text{ where } R_T = F_S.$$



Also for sails in air and an apparent wind V_A in knots,

$$C_S = \frac{293 \,.\, F_S}{A_S \,.\, V_A^2}\,.$$

Combining and reducing,

$$\frac{V_B}{V_A} = 0.585 \; \frac{\sqrt[2]{A_S}}{\sqrt[3]{W}} \cdot \sqrt{\frac{C_S}{K_H}} \cdot \qquad \text{(A).}$$

for any given $\frac{V_B}{\sqrt{L}}$ and course.

Equation (A) is highly important since it predicts a sailing craft's overall performance in terms of the ratio of boat speed to apparent wind speed on any course. One must know only the sail coefficient and the hull coefficient at a given $\frac{V_B}{\sqrt{L}}$, also the sail area and craft weight.

Using equation (A), Table II, Fig. 4, together with a sail area of 80 square feet and a weight with crew of two totalling 507 pounds, permits calculating the overall performance for all courses. A polar curve of the results constitutes the right-hand apparent wind portion of Fig. 5. The left-hand, true wind portion of Fig. 5 was obtained from the following two conversion formulas:

$$\frac{V_B}{V_T} = \frac{V_B / V_A}{\sqrt{1 + \left(\frac{V_B}{V_A}\right)^2 - 2\,\frac{V_B}{V_A}\cos\left(\delta_S + \delta_H\right)}} \cdot \qquad \text{(B).}$$

Where the true wind to course angle is $\gamma°$,

$$\tan \gamma = \frac{\sin(\delta_S + \delta_H)}{\cos(\delta_S + \delta_H) - \frac{V_B}{V_A}} \cdot \qquad \text{(C).}$$

On the left-hand true wind curve of Fig. 5, is a graphical construction which is simultaneously perpendicular to the wind direction and tangent to the performance curve. The point of tangency determines the required course to the true wind and its speed ratio to produce the best "speed made good" directly into the true wind. The latter value, in terms of $\frac{V_B}{V_T}$, equals 0.25 for $\frac{V_B}{\sqrt{L}} = 1$, read at the intersection of the perpendicular with the wind direction. Converting this course, by means of equation (C), to the apparent wind reference,

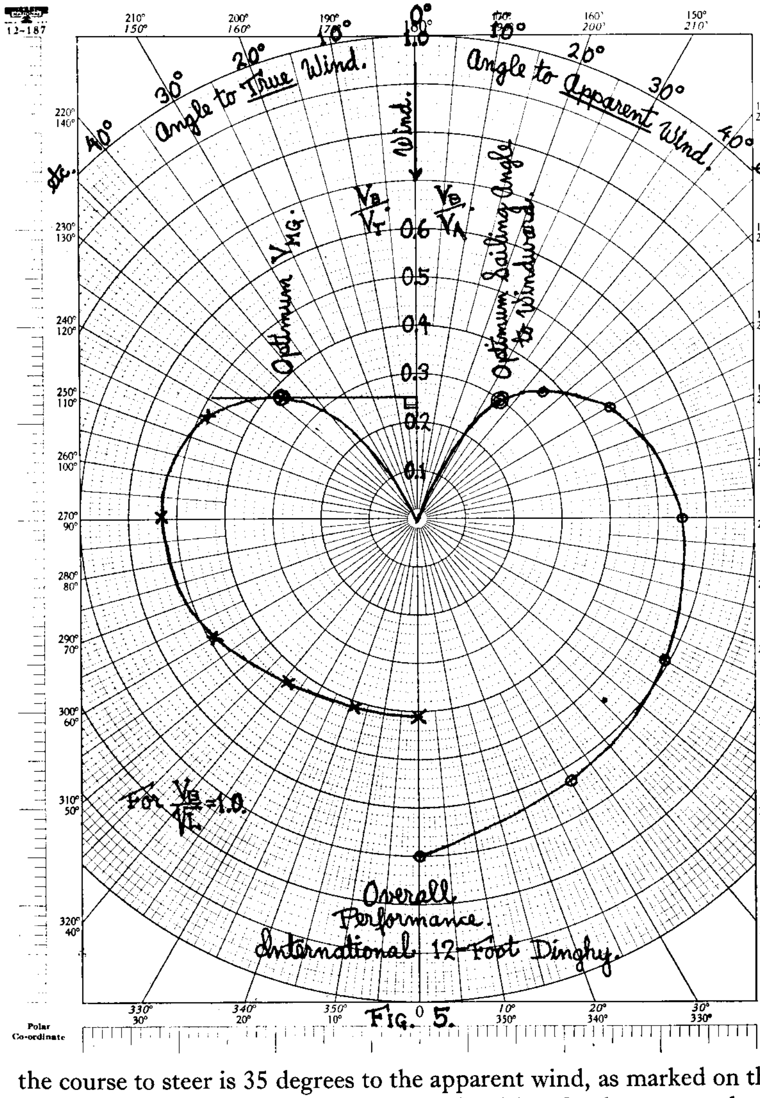


FIG. 5.

the course to steer is 35 degrees to the apparent wind, as marked on the right. Any attempt to achieve this result with a fixed course and sail adjustment, as in the Gimcrack method, seems subject to serious error.

Returning to equation (A), giving the overall performance, it is seen that the ratio of the fixed values $\frac{\sqrt[2]{As}}{\sqrt[3]{W}}$ is vital to the performance. When the coefficients for a hull and sail are unknown, a good "rule of thumb" criterion of its potential performance is this ratio, where W includes the weight of the crew. Being dimensionless, this ratio is independent of size. This is not true of the ratio of weight per square foot of sail used by some authors. The writer uses the stated ratio for cataloging all sailing craft. It is remarkably consistent with known performance comparisons.

The ratio of total coefficients $\frac{C_S}{K_H}$, in equation A, is identical with the ratio of their drive and resistance components $\frac{C_S \cdot \sin \delta_H}{K_H \cdot \sin \delta_H}$.

$K_H \sin \delta_H$ for $\frac{V_B}{\sqrt{L}} = 1.0$ is plotted with dotted lines in Fig. 4.

Since this resistance component is nearly constant, especially over small ranges of δ_H, maximizing only the drive component by graphical means to obtain optimum speed, is warranted. This is within the accuracies of the empirical measurements. The resistance component is not precisely constant as its drag angle is varied due to a change in the water flow-pattern.

A further use of equation (A) is that it makes possible the determination of hull coefficients at full size and quite independent of the sail being used. Full size towing is not necessary $\cdot$ $\frac{V_B}{V_A}$ for the course and speed is determined from full size performance tests, as described beginning on page 36 in A.Y.R.S. No. 56. C_S for the course is determined by full size tethered sail tests as described beginning on page 23 in A.Y.R.S. No. 40. By substituting all of these values, for the course, into equation (A), one can solve for the unknown value of K_H for any course.

Such coefficients could be compared with those of competitive hulls. Also, the accuracy of hull coefficient determinations, by corresponding models tested in a towing tank, can be assessed. This is seldom done in current practice.

Final Remarks:

It seems quite proper that all of us might use the best technical procedures available even if faults are known to exist. The results could be more useful than none at all. The Gimcrack Coefficients possibly have been in this category all these years.

If my criticisms were to be merely destructive, this article never would have been written. As reasonable and supposedly improved methods are now proposed, I hope that my criticisms of the Gimcrack methods will be considered constructive.

Dear John,

At the last Salon de la Navigation de Plaisance in Paris, le Centre Nautique de l'Aber Wrac'h, helped by the National Centre for Scientific Research (C.N.R.S.), showed a set-up designed to simulate the effects of different courses to the pupils of the sailing courses of this club.

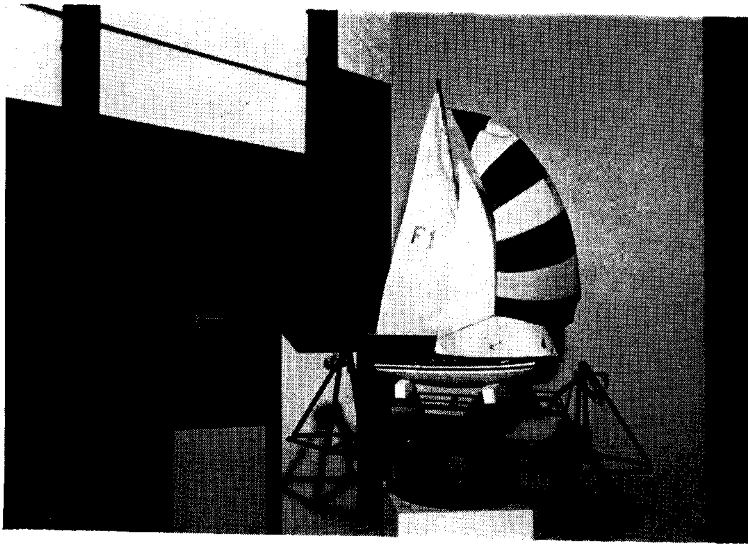


Photo I.

The set-up consists of two items. The first consists of a cradle which is free to heel and which can be rotated in relation to a jet of air from a fan, fitted with air straighteners. Strain gauges placed fore and aft register the thrust and side force on the cradle supports and also the position of the sail force in height. This apparatus is a model of an installation which it is hoped to make at full size to support a dinghy.

The second item is, in my opinion, more interesting. (ph. 3). It is a recirculation tank working as in the drawing. The model is free, within certain restraints, in yaw, heel, leeway etc. The model is acted on by a fan which can be rotated around it (as well as around the tank) to give wind blowing from all directions, this was not done at the Salon for reasons of space.

For a fixed wind and water speed, equilibrium is obtained when the side forces (given by two gauges) are nil, and the thrust force is also nil.

The side forces are reduced to nil by the adjustment of the sails and rudder, the thrust forces by adjusting the wind and water speeds.

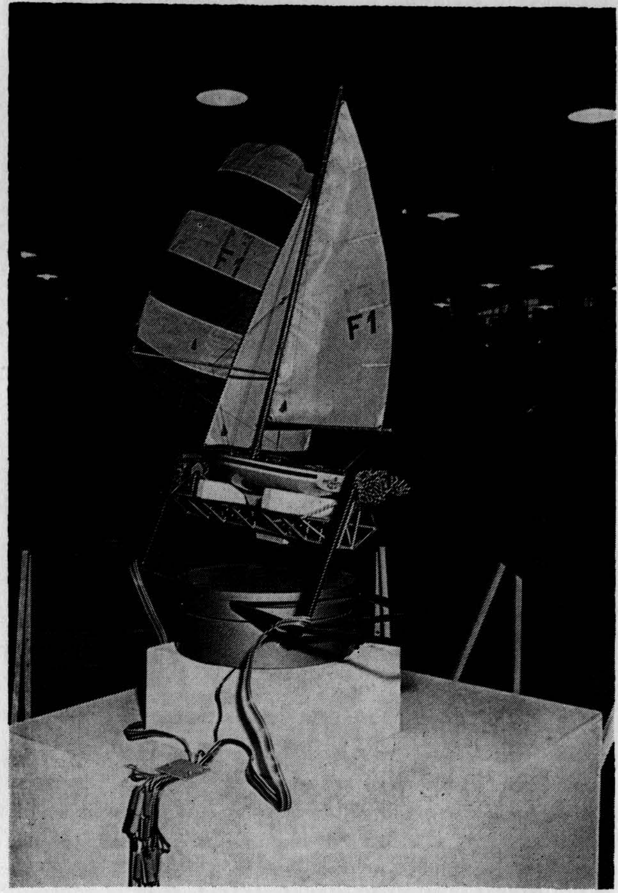


Photo II.

Photo 4 shows the connections of the boat. Photo 5, the positions of the forces measured while photo 6 shows the control panel.

It follows that, from a device for teaching which has no pretentions to precision, one could hope for the creation of a research apparatus of great value.

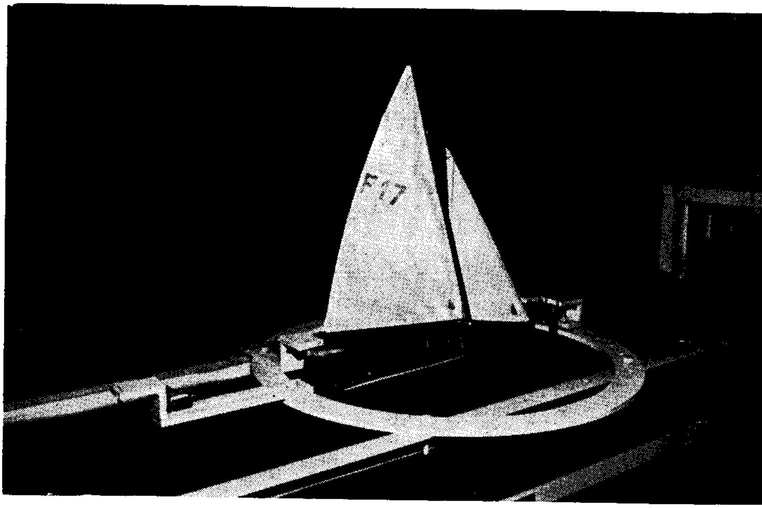
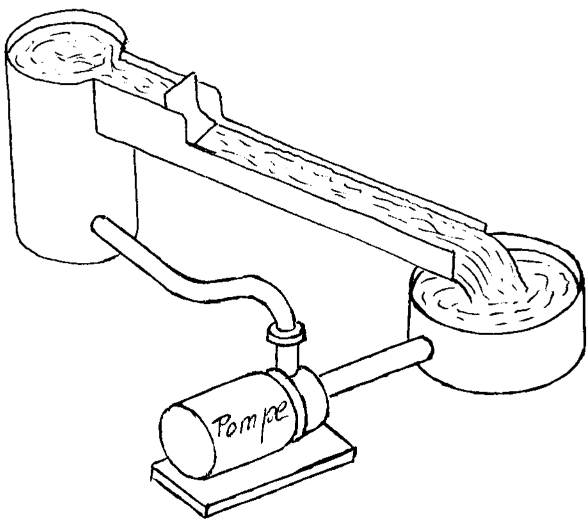


Photo III.



As regards standardisation of symbols, I would like to add:

α angle between the sail and the apparent wind.

ε angle of the resultant R (the sail force) with the axis of the boat.

R the resultant sail force.

ε and R are the two factors which allow the polars to be drawn.

PIERRE GUTELL.

26, rue Chaudron, Paris Xme.

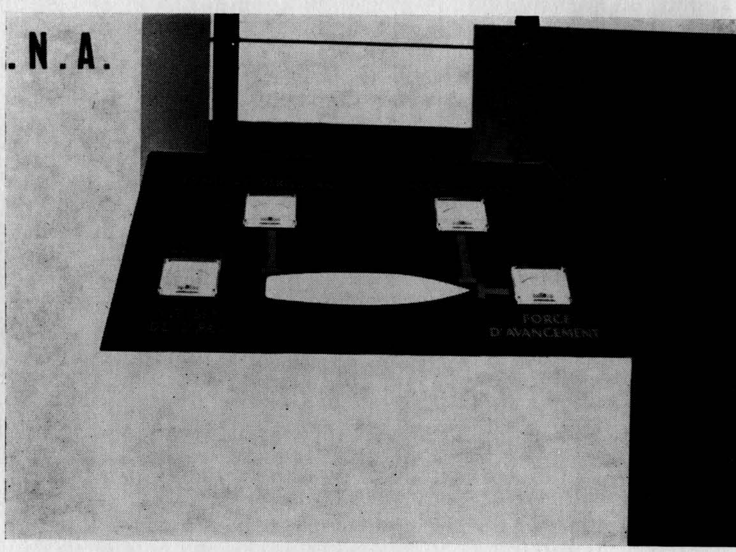


Photo. IV

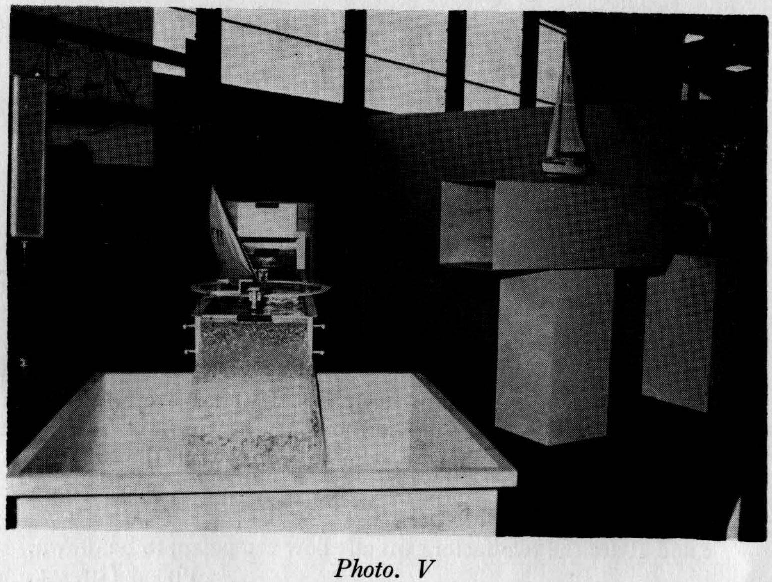


Photo. V

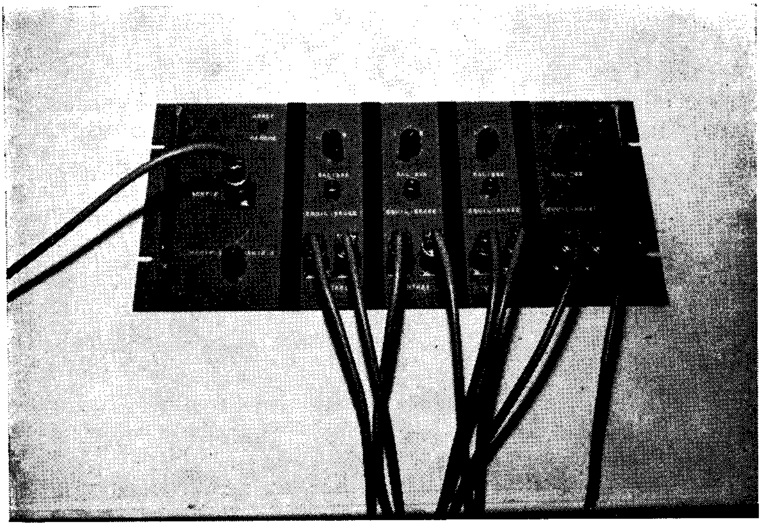


Photo VI.

Dear John,

Your letter of 25.1. impresses me. It seems you never lose an occasion to inspire and actuate everybody you come in contact with. You write that you are trying hard to get someone to invent hydrofoil stabilisers for a narrow, semi-ballasted monohull.

At present I live too far from the sea to do any full sized experiments on hydrofoil stabilisers, and my comments will be from purely theoretical considerations.

I think I can see your point: You want a hull that is safe, though barely ballasted to right itself from a 90°-heel. And then, to achieve good speed you want to give this hull a rather large sail-area, aided by hydrofoil stabilisers.

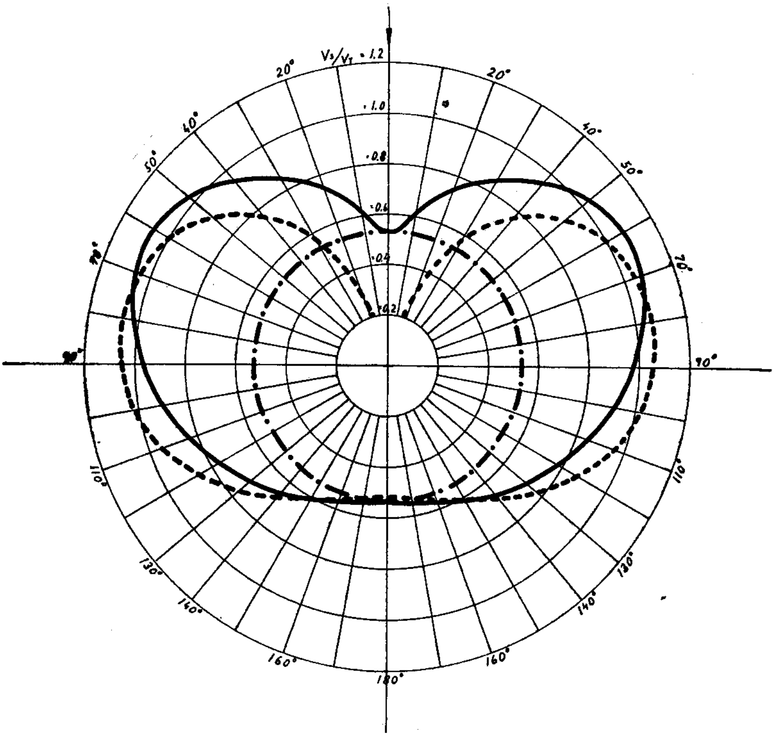
Personally I would not choose this type of a boat: Hydrofoil stabilisers don't work before they have adequate speed, and adequate speed is not acquired before a sail has had an opportunity to give full thrust and acceleration for some seconds, and without the help of the righting-moment from a stabiliser. In a steady wind such a combination might slowly be built up, but when are winds steady enough?

This Easter I have taken the opportunity to turn over the leaves of a number of the older copies of the A.Y.R.S.-publications. I can't keep from wondering what a marvellous collection of beautiful boats we here have, and what a sum of theoretical and practical knowledge.

Has anyone thought of writing a complete and detailed index, let us say for the publication numbers 1 to 60?

In the publication no. 58, Terance Surman gives a plausible explanation for Birkett's lack of success on his model *PROA* described in no. 51. But what I cannot understand, is where Surman found what he calls "typical CL and CD curves, for varying angles of incidence." I have never found data over an airfoil so extremely bad as his. His value for the drag coefficient at 41° is about twice the value of the maximum lift coefficient. And his L/D ratio at 16° is not more than 1.5. I really doubt if such values for an airfoil have ever been measured. The profile of "*BOTJE III*'s" outrigger pictured by Taylor in no. 47 certainly has a much better figure. It seems to me that Surman must have forgotten to divide his CD-values by some factor of 10. And in that case the calculation of the stabilising-moment will show a much more favourable picture.

The windmill driven model boat of no. 41, and the full sized boat of no. 58 certainly are interesting. I have done quite a lot of calculations along these lines, and the results are fascinating. I have seen (I can't remember where) that someone has placed an autogiro rotating



wing as a sail on a small boat. Something in between a windmill- and a rotating-wing-boat gives impressive results on paper. Gessow & Myers in "Aerodynamics of the Helicopter" give detailed formulas for calculating the characteristics of rotating wings. This includes all transitions from a helicopter-rotor absorbing power, through an autogiro rotating freely, to a regular windmill yielding maximum power. The computations are extremely elaborate and timeconsuming, and should be well suited for a modern electric computer. I have had the work lying around for about three years, filling up the columns now and then in spare hours. The results are condensed in the enclosed polar diagram.

The dotted line represents the theoretical speeds of a regular sailing boat with a high-efficient 5° sail (wingsail).

The dot-dash-line is for a boat driven by a screw powered by a windmill always with the axis of rotation pointing directly into the apparent direction of the wind.

The solid curve is for a boat driven partly by a screw and partly by the wind-forces directly on a windmill with the axis pointed in that direction which gives the best resultant speed forward.

The boat-hulls are assumed identical, and the areas of the wind-mill discs and sail are of the same size. The windmill-blades are assumed to be of variable pitch, and the gearing between the windmill and the screw is assumed to be continuously variable. The curves give the speeds when every variable is trimmed to the optimum. Losses in the friction of the mechanical transmissions and of the screws are taken account of.

How is Peter Tangvald doing it with his *DREAMBOAT*? I suppose your correspondence with him has continued. Will we be having more of those inspiring letters between you in the publications?

Yours sincerely,

FIN K. L. UTNE.

Fjellveien 7, Askim, Norway.

Ed.: I have not heard from Peter for some time. He sailed *DOROTHEA* to B.P. 270, Cayenne, French Guyanne, SA., took a house and is now building his boat. His letters to me were written while he was making up his mind which boat to build. Now, when he is being practical, he presumably has little time for letter writing and discussions of design are not relevant.

AEROPLANES AND GEESE AND SAIL DESIGN

Some Thoughts and Notes on Aerodynamics and Sails

BY

R. R. A. Bratt, M.A.(Cantab.), C.Eng., A.M.I.Mech.E.

North End Works, Millers Close, Dorchester, Dorset

By Courtesy of the Editor Yachts & Yachting

When a yacht is sailing close hauled or reaching, with the wind making a small angle of incidence on the sails, the wind is deflected and the change of momentum in the air gives rise to a force roughly at right angles to the plane of the sail. This force can be considered as consisting of two forces at right angles. We can think of it as a thrust force in the direction of motion relative to the water and a side force. The side force is undersirable and is usually cancelled out by fitting the yacht with a keel or plate, which generates force in the opposite direction. The forward thrust force is available to overcome wind and water resistance of the boat and sail as a whole.

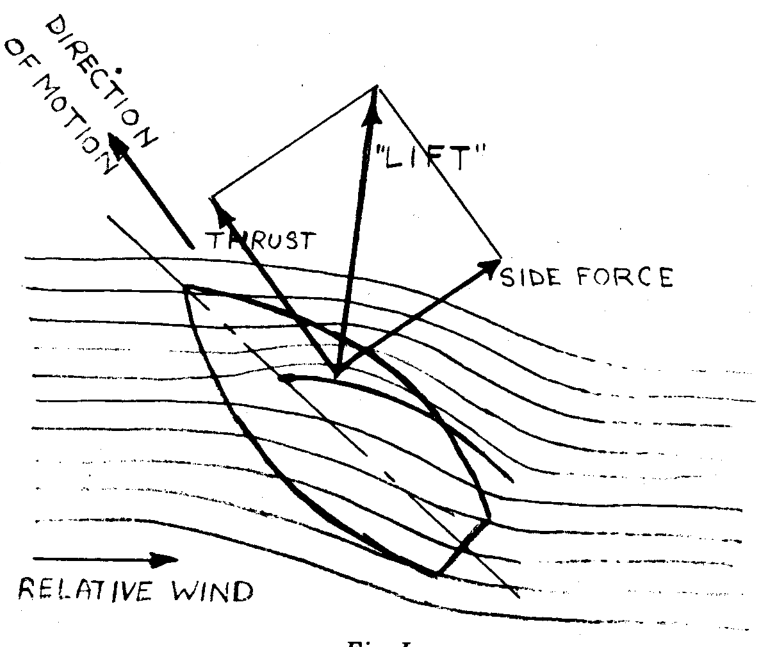


Fig. I.

This situation can be depicted as figure 1. Diagrams showing the air flowing over a yacht sail in this manner can be found in numerous books and articles on sailing. The diagram is probably correct for a narrow horizontal strip of sail about a third of the way up. It is probably correct for a large part of the sail if one considers all the airflow as resolved into a horizontal plane. The diagram is in two dimensions but the airflow occurs in three.

You are entitled to ask what happens to the air after it has been deflected. Does it stay put? Does it bounce back? What is the nature of the disturbed area of air in the lee of a yacht?

In the case of an aircraft it is accepted that the flow consists of two vortices which trail from the wing tips or just inside the wing tips as Fig. 2. Vortices usually consist of a slowly rotating volume of fluid with the speed of rotation increasing towards the eye. In water the

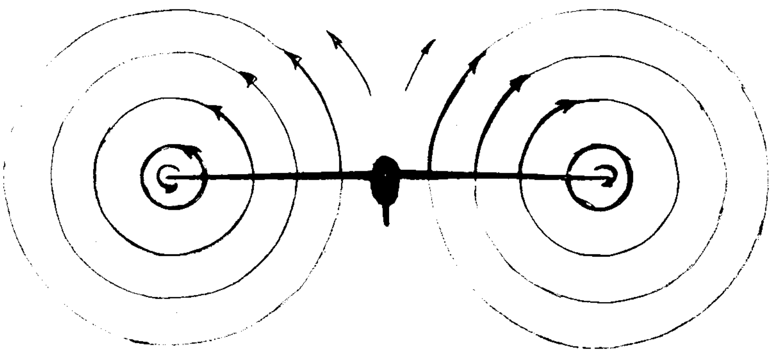


Fig. II.

speed of rotation in the eye can be so great that a sinuous vapour cavity forms; and in the eye of some tropical storms and depressions condensation occurs making the most dangerous part of a tornado sharply visible. Condensation trails can occasionally be seen at the tips of an aeroplane wing under conditions of heavy loading and high humidity. The most familiar example is the vortex as the bath water runs away, and the thin high speed centre fills with air.

The path that an aeroplane has followed consists of a region of down deflected air. Trailing from near each tip is a vortex centre around which the disturbed air is rotating. Each side of the path there is a region of rising air. I read a report before the war of a sailplane having maintained height by flying in formation behind two Lysander aircraft which flew slowly side by side. Geese make use of the zone of rising air behind a leader, and it is an interesting thought that the bird on the right of the leader probably makes a stronger vortex on its right hand side than left. Thus the third bird finds it desirable to fly to the right of the right hand bird and so on leading to the familiar V formation in which none of the geese consider it worth flying in the middle. That much a diversion with nothing to do with yachts of course.

The vortices behind a wing represent a major loss of energy and they give rise to what is known as "induced drag." The induced drag of a wing is the part of the total drag which is associated with developing "lift." Whereas the other forms of drag are greater at higher speeds the induced drag of an aeroplane is greater at lower speeds when the angle of incidence is greater to maintain lift.

You can look at this in two different ways and say a slow moving aerofoil must be set at a bigger angle of incidence to the air in order to maintain a given lift force; or you can say that a particle of air is given a longer impulse and deflected further when it takes a long time to pass the aerofoil. Expressing it the latter way you can see that there is advantage in making an aeroplane wing of big span and small chord, i.e. of high aspect ratio.

The energy loss which occurs in this way is known as tip loss. You can if you like consider it as flow around the tip due to the pressure on the lower side of the wing being higher than on the top surface, though as we have seen the flow is much more than just a sort of air leak around the tip. This energy loss can also be minimised by making a wing eliptical as was the war-time Spitfire, but the cheaper expedient of making wings tapered is usually adopted.

In yachts there has been a tendency over many years to higher aspect ratios. The higher ratios have presumably been found advantageous though the data is presumably not available to make the optimum calculable as it is with aircraft. Sail height has the same structural disadvantages as excessive span in aircraft. A yacht with a very tall rig, though, meets two further snags. Means have to be found of holding it upright against the increased overturning moment, and the sail tends to twist out of the wind as distance from the boom increases.

Yacht designers seem to consider that the hull of a yacht is equivalent to the fuselage of an aeroplane and that the sail is equivalent to one wing projecting from the side of the fuselage. I myself do not see it that way, but in the light of the things I have stated I feel that a yacht sail is probably equivalent to a pair of wings, but having an upper tip and a lower tip.

In a boat like the *FINN* where the sail is carried down close to the hull it may be reasonable to consider the sail as equivalent to a single wing but I will return to this.

What I believe is that flow over a triangular sail forms two vortices just the same as an aeroplane. I visualise them as dividing at a neutral line about a third, perhaps only a quarter of the way up the sail as Fig. 3. I visualise the upper vortex as a large slow rotating thing

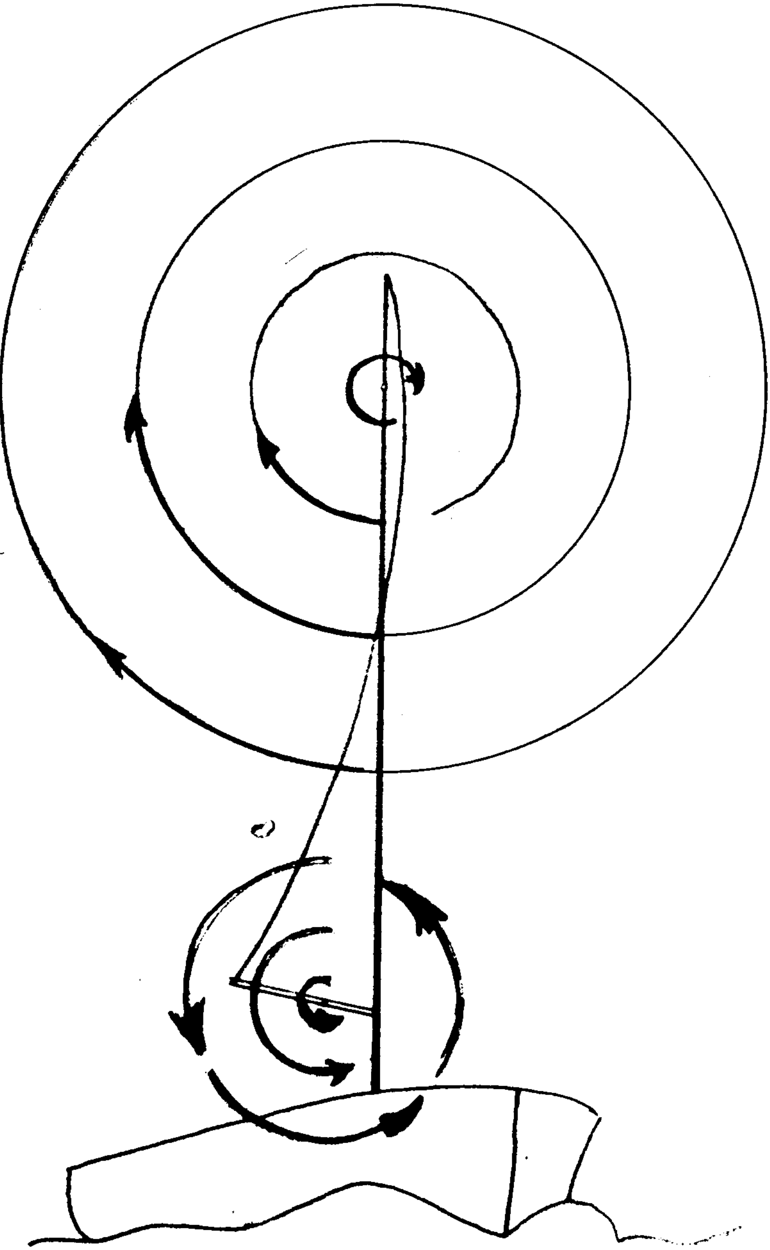


Fig. III.

centred well below the top of the mast. It may be considèrably broken up by the top of the mast and other distrubances. The lower vortex would be a smaller and more vigorous affair rotating roughly along the line of the boom.

A Bermudan yacht sail twists from bottom to the top. A certain amount of twist is desirable because the relative wind is slightly different at the top to the bottom. Sails commonly twist much more than this so that the top is making a very small angle of incidence to the wind, while the bottom is at an altogether excessive angle of incidence. In spite of the large angle of incidence the bottom of the sail is not stalled but spilling some of its air around the boom. Air not spilled receives a prolonged impulse into an outer layer of the vortex. When the twist in the sail is very severe the lower vortex may conceivably break up into a series of vortices, general turbulence.

Because the lower vortex is small there is plenty of room for it to form between the sail and the hull, but I suspect that it is not the

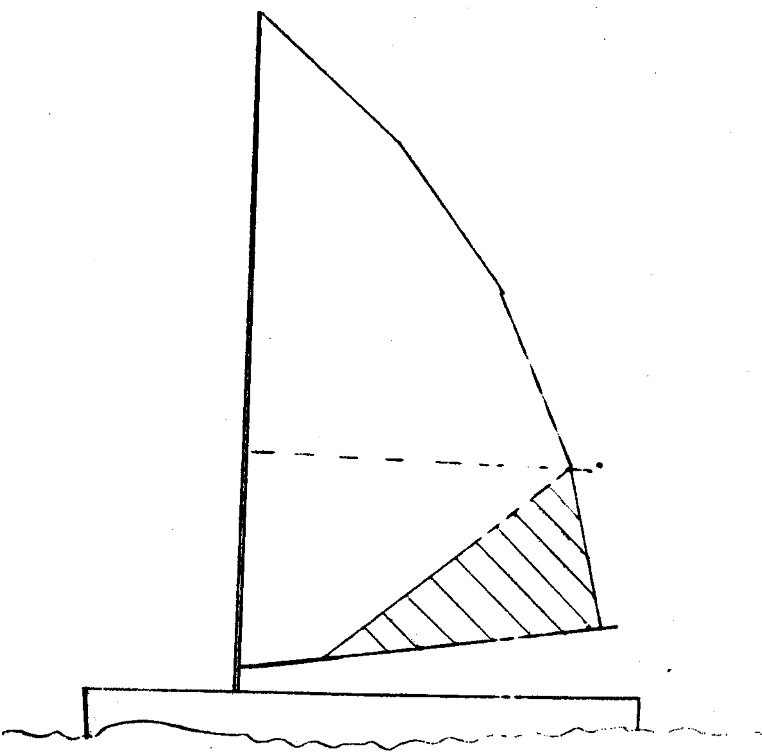


Fig. IV.

listance between the boom and the deck which allows it to form but the ieight of the boom above the sea. Thus using a very low boom might estrict the lower vortex (making the sail more like one side of an ieroplane) but it would not prevent it.

The solution which is interesting me is to move the boom away rom the bottom of the sail so that the widest part is some way up and he sail tapers towards both tips. This has some notable effects. The strong lower vortex is greatly reduced, a higher aspect ratio can be btained without the sail twisting out of wind and very little twist ccurs from bottom to top.

The boom of course has to be curved to allow the sail to fall into camber whichever side the wind is on, and the sail attaches to the oom only at the clew.

People seeing my experimental sails remark that the centre of ressure must be higher than an ordinary sail. If this is so then I nust add that if the sail is more efficient, which I believe it is, then we hall have more forward thrust with less side force. What we have in ffect done is to remove the triangle shaded in Fig. 4. This triangle ying nearly in line with the boat when close hauled, and always at a evere angle of incidence presents a large side force with a very small orward thrust. This triangle is in effect removed and then the sail lropped to deck level, thus reducing the overturning moment.

If the side force is reduced it could mean a small increase in fficiency and speed; but a smaller overturning moment would mean hat any particular hull could carry a bigger sail, which is one fundanental way to make a boat go faster.

TANK TESTS OF 10 SQ. METER CANOE HULLS

BY

J. D. LAWSON, PH.D.

AND

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These tests were made on one-tenth scale models (about 16 in. L.O.A.) in a 32 in. wide flowing water channel and in a 6 in. wide perspex flume. Three models were tested of the following shapes:

Model "B"—A fully hard chined model.

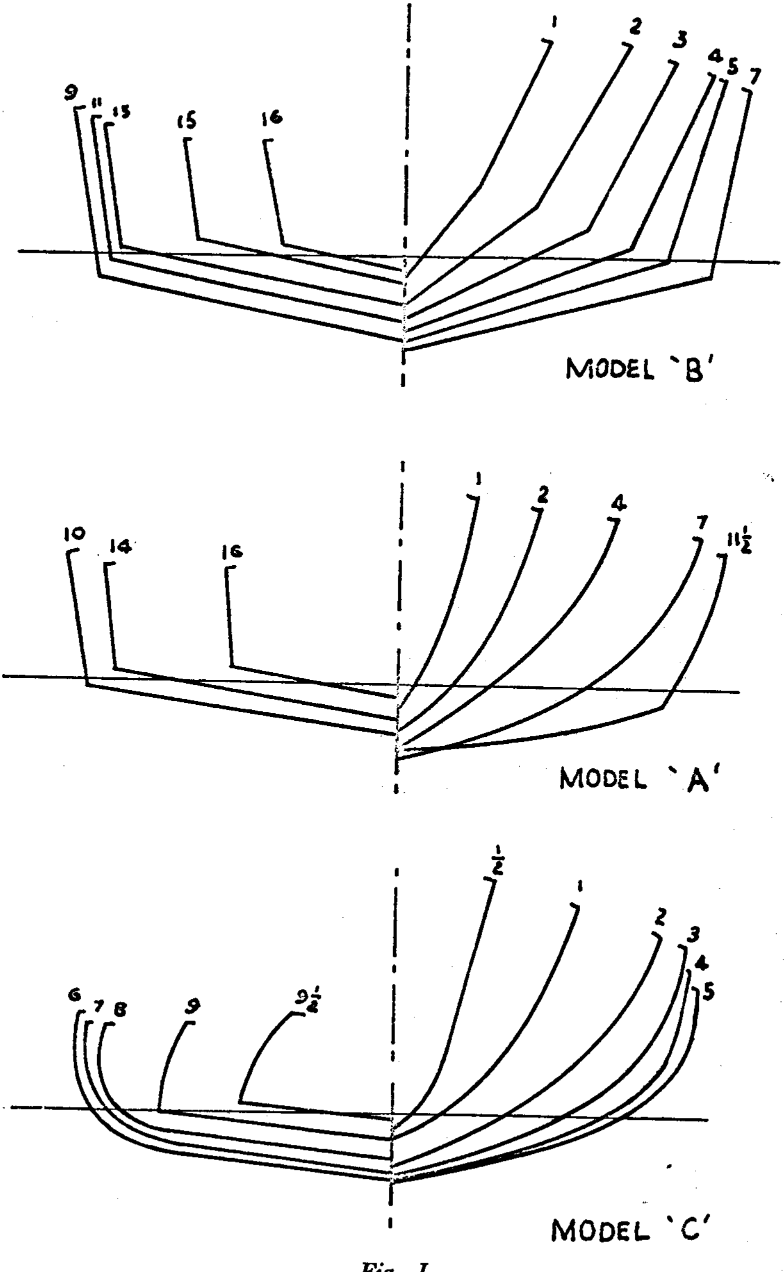

1
2
3
4
5
7
9
11
13
15
16
MODEL 'B'
1
2
4
7
11½
10
14
16
MODEL 'A'
½
1
2
3
4
5
6
7
8
9
9½
MODEL 'C'

Fig. I.

Model "A"—A round bilge bow with hard chine midships and fter sections.

Model "C"—A round bilge model with hard chine stern.

Measurements. Only two things were measured, drag and water elocity. The drag was measured by a light-weight balance type ynamometer (Fig. 2). The drag force was balanced by sand placed 1 the scale pan which was later weighed. This was done 5 times for ach reading. The water velocity was measured by an Ott current ieter fitted with an electric revolution counting device, 3 times per est.

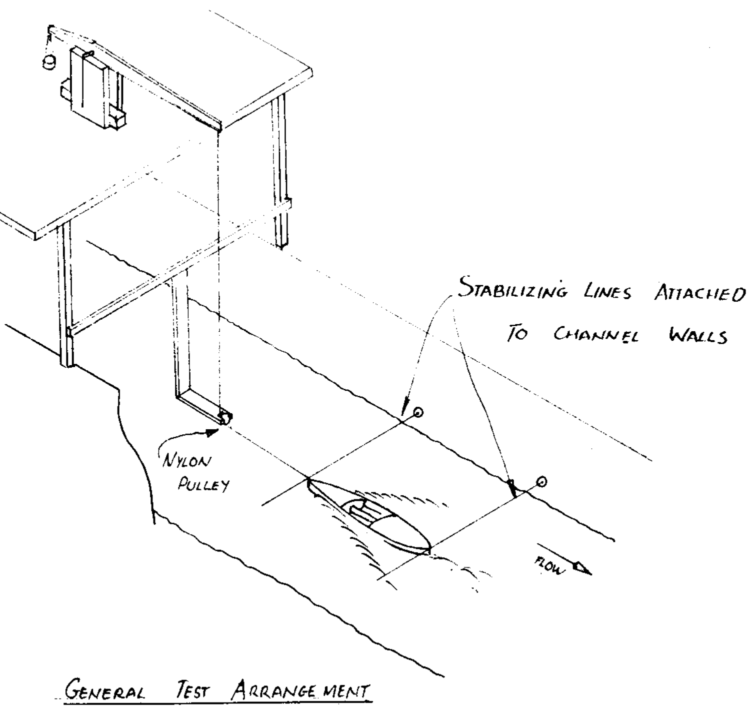


Fig. II.

Wetted Area. This was worked out for various angles of heel nd is shown in Fig. 3. Model B, the hard chine has most wetted area vhen upright and least when heeled to 15°. Model C, the rounded ilge has least wetted area when upright which it only loses at 15 legrees of heel.

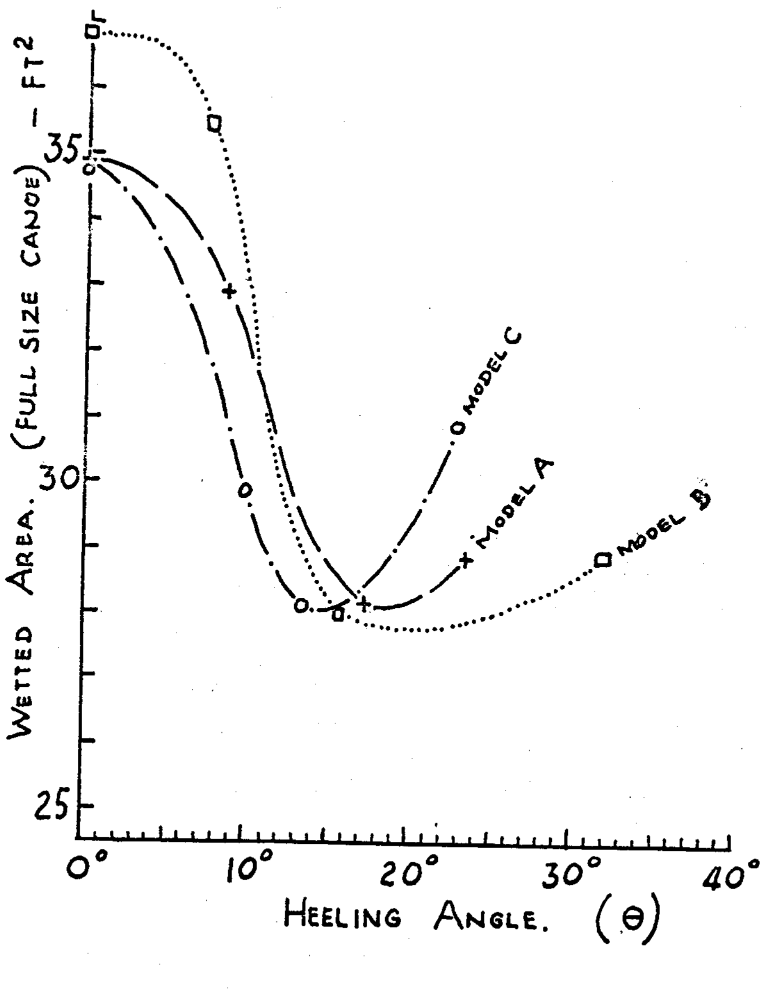


FIGURE 3. RESULTS OF WETTED AREA TESTS

Residual Resistance (Wave-making) when upright. Fig. 4 shows that the model A, hard chine, has the greatest residual resistance up to 4 ft./sec. while model C, round bilge has the least. Above 4 ft./sec. Froude Number 5 the hard chine model A starts to plane and its residual resistance gets less than round bilge C but the increase in

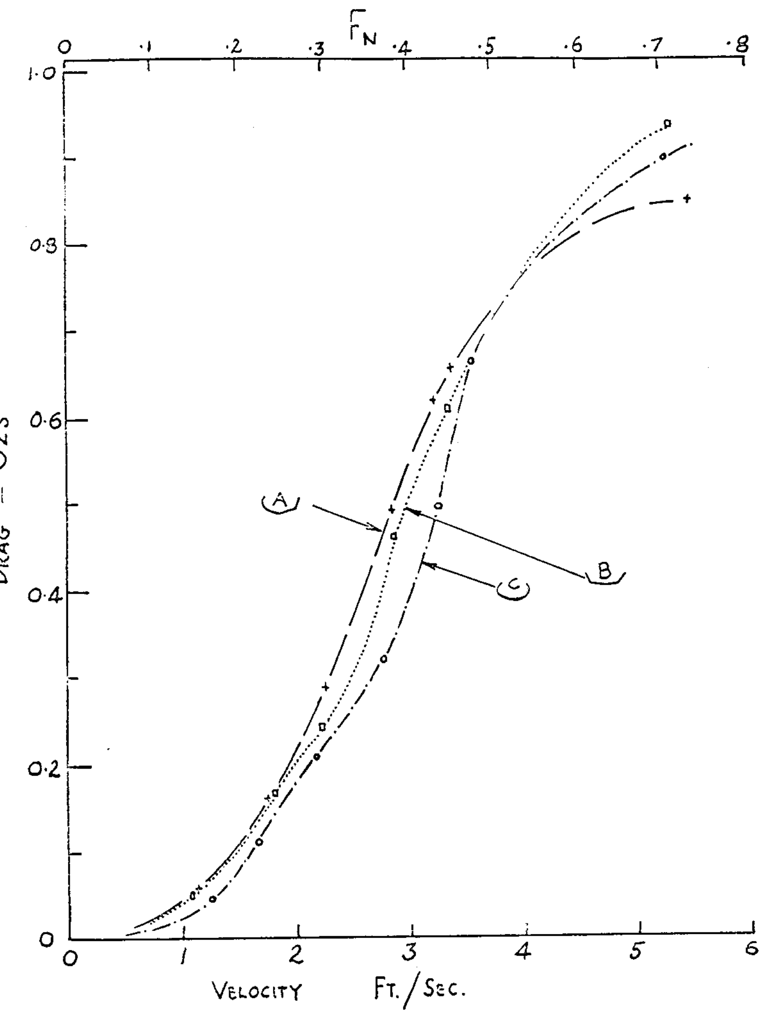


FIGURE 4 RESISTANCE CURVES FOR THE MODELS

wetted surface would still be present, giving the round bilge hull the advantage during the majority of sailing speeds.

Summary. The round bilge hull (C) will be faster than the hard chine hull (A) due both to wetted surface and residual resistance being less up to Froude number 5. Above that speed, the residual resistance of the hard chine hull (A) gets less but the wetted surface remains higher for some time.

Rob McConchie stresses two features of his paper:

1. The variations of wetted area obtainable by deliberate heeling and

2. The advantages of careful waterline profile design in respect to the magnitude of any wave trains that are formed, bearing in mind that *the energy lost in making and maintaining waves is proportional to the wave height squared and the wave length.*

An interesting feature of these tank tests is the fact that laminar flow in a flowing water test tank was used. The applicability of the method to tests of full sized yachts in tidal streams or fast-flowing rivers should be noted.

A copy of the full paper is available from Woodacres on loan to members.

TWIN BILGE KEELS

Bilge keels and bilge rubbing strakes have been used for many centuries to let boats and ships take the ground and lie on the bilge without breaking the frames or planking. In this case, they are merely an external stringer to distribute the strain along the hull over many frames.

With the advent of the motor boat, either steam or internal combustion, rolling became a problem and deepish bilge keels were used to damp this out as quickly as possible.

The first application of which we know, however, when twin bilge keels were used by a sailing vessel actually to prevent leeway was in the four masted barque *ARCHIBALD RUSSELL*, built by Scotts of Greenock in 1905. Captain MacLean, one of our members served in her in 1937 on a voyage from Port Germein, South Australia to Kemi, Finland, via Barry Dock where the wheat cargo was discharged. Square riggers make a lot of leeway when close hauled and lightly loaded and it is assumed that the bilge keels were fitted to prevent this. When fully laden, there is enough lateral resistance for the maximum windward performance.

THE HYDRODYNAMICS OF BILGE KEELS

BY

JOHN MORWOOD

Introduction. The fin keels of all yachts, except for dagger boards of an aspect ratio of 3:1 can never be said to function as true hydrofoils. The aspect ratio is too low, and often far too low. This means, of course, that "End losses" under the keel create such a deep eddy low down in the water that the drag is excessive. However, in practice, this is not quite true if we consider the figure of 10° given us for the "drag angle" of a twelve meter (which is quite good) and the only explanation for this is that a good deal of lateral resistance is coming from the "canoe body" of the hull itself.

Very Low Aspect Ratio Keels and Centreboards. Amongst traditional boats, the *NEW HAVEN SHARPIE* has a centreboard about four times as long on the keel as in the drop. It is of a triangular plan form and allied to a long narrow hull of box sections—flat floor and almost vertical sides. Such a centreboard has an aspect ratio of 1 in 8 and this fantastically low figure bears absolutely no relationship whatever to a hydrofoil—and yet such a board presumably allows the boat to point up well to windward.

However, what is even more relative to our argument here is the use of very low aspect ratio keels on multihulls which apparently allow very good windward performance. Now, the waterlines of multihulls are the shape of excellent hydrofoils in their fore part as regards thickness chord ratios and one can only assume that the low aspect ratio keel makes the hull function as a hydrofoil by preventing *the Hull's "End Losses."*

Conclusion. Low aspect ratio centreboards and fixed keels are capable of acting as "fences" to prevent sideways waterflow from occurring across the hull. That is, they direct the waterflow fore and aft along the hull. In the case of the *NEW HAVEN SHARPIE* and the multihull, the narrow waterlines can then develop good hydrofoil properties.

Twin Bilge Keels. If we now come to apply the above arguments to similar "fences" placed one on either bilge of a monohull boat, we see that the following differences apply:

1. The hull is far fatter than a multihull. This means that
2. The hull lines will not be those of a good hydrofoil and
3. Surface waves will appear at high speeds.

The Design. If the bilge keels are not to function as hydrofoils, there is no point in their having any thickness and therefore thin steel plates will be perfectly satisfactory. As they are to act as "fences" they should be placed exactly in the waterflow, starting near the bow where the keel angle has just separated widely from a narrow V. Now, the waterflow along yachts is different at different speeds. In light winds the water speeds up at the maximum section and slows again aft and, with a semi-circular hull section, the particles of water would seaparate radially from the centres of the sections. In strong winds, however, the speeding up of the waterflow at the maximum section creates a negative pressure and sucks the surface water down, thus giving a hollow or hollows to the surface water according to the speed. The particles of water then flow in a wavy motion more or less in the vertical plane from fore to aft and the extra water added by the "suck-down" causes even more speeding up of the water below the hull and still more "suck-down."

From the above considerations, the bilge keels should be placed in the waterflow in light winds i.e., at right angles to the surface of the hull and radially from the centre of a semi-circular section—I have no idea where they should be placed with a normal design. Their plan form should be a convex sweep and, on analogy with the *NEW HAVEN SHARPIE*, there seems to be no point in taking them aft of 60 per cent of the L.W.L. of the boat, but this might be necessary to carry ballast.

Performance expected on the Arguments. In light winds, because the bilge keels are placed in the fore and aft waterflow, they will have almost no improving effect on the hull's hydrodynamics and will merely function as very low aspect ratio hydrofoils in the leeway. The lateral resistance will therefore be very poor with a fat hull but will improve with a thinner one. In medium winds, when surface waves are beginning to cause resistance, the bilge keels will tend to prevent them by interfering with "suck-down" and the head resistance will be kept lower so the performance will be about equal to the single keel yacht. In strong winds, the vicious circle of "suck-down" will be broken and top speeds will be much better than with the single keel.

Conclusions. Bilge keels act as "fences" at most times and they therefore should be thin plates and extend a long way forward. Their main function is to prevent "suck-down" and hence surface waves and this explains their greater value in strong winds.

John Lewis' SHARPIE. John Lewis—a well known model yachtsman—has designed a model yacht with box sections and twin keels with ballast. This boat won her class Championship against the usual model yachts and was made at full size by "Blondie" Hasler as *SUMNER* in which he sailed in the Round Britain Race. The fallacy of this is, of course, the usual model one in that models usually sail in scale gale conditions when the twin bilge keels do not show up their inefficiencies. Nor does the box sectioned hull.

As described by Chapelle in his book *Small American Sailing Craft*, the box sectioned hull is very sensitive to shape and deviations from that found best are generally poor. Bilge keels would, however, be very easy to provide for such a hull as the topsides can so easily be extended down a few inches to give a low aspect ratio keel at each bilge. If each section is given a beam of twice its immersion, the downwards extension of the topsides could be carried right to the bow and they would be in the light wind waterflow. One cannot, of course, say how such a hull form would sail or how one would place the ballast but at least it would be an easy shape to build both for models and full scale.

Dear Dr. Morwood,

In regard to your proposed article, "Hydrodynamics of Bilge Keels," I like your viewpoint that a low aspect ratio keel really serves as a "fence" for the hull which acts as a hydrofoil. This would be an excellent project for someone who has access to a laminar-flow towing tank and who is vitally interested in the shallow tidal-area sailing problem.

Low aspect ratio hydrofoils seem to have larger lift coefficients and better lift-drag ratios than equations based on the "Lifting-line Theory" would lead us to believe. Some theorists contend that, for aspect ratios less than one, the "trailing" rather than the "bound" vortices provide the performance for submerged foils.

Consider water skis which obtain no lift from their upper surfaces. In spite of an extremely low aspect ratio, a 150-pound skier may feel a line pull of 35-pounds at medium speed. This means a lift-drag ratio of 4.3. Also, water impact on a wetted surface area of less than 5 square feet is supporting the weight of the skier.

Sincerely,

EDMUND BRUCE.

Lewis Cove, Hance Road, Fair Haven, New Jersey, U.S.A.

THE MOST "EFFICIENT" YACHT

BY

JOHN MORWOOD

Definition. This term "Efficiency" is almost impossible to define to the satisfaction of everyone. It need not mean speed over the square root of the length in a given wind strength because this doesn't take into account the sail area. Nor, need it mean speed over the square root of the sail area or speed by any of the rating rules so far devised. This leaves us in the doubtful position of simply defining "efficiency" for any present purpose.

For this article, therefore, I am going to define "efficiency" as "The minimum course pointing angle for best Vmg in light winds." A "light wind" in turn would be defined as a wind which does not "press" a yacht.

The result of this definition is that we have abolished all ballast because, if the yacht is not to be pressed in light winds, the ballast is not necessary. It is a point to start from.

The Beam-length Ratio. In *Basic Research* (A.Y.R.S. No. 45), Edmond Bruse showed that with semi-circular hull sections, and hulls of equal weight, a beam-length ratio of 8:1 was best for fairly heavy hulls, in running resistance. This ratio will also give a poor "hull drag angle" or lateral to head resistance ratio without the help of a keel or boards.

The Hull "Master Section." The semi-circle gives minimum wetted perimeter for its displacement but the displacement needed for such a section would be excessive for a monohull and we cannot have any ballast by our definition. We also need stability and the semi-circle doesn't give us much. We should then consider the semi-ellipse and a breadth to depth of 4:1 for this only increases the wetted perimeter by 10 per cent at the "Master section." possibly only increasing the total wetted surface by 5 per cent. The increase in running resistance may be even less than this.

Unfortunately, we do not know if the Bruce tests hold good for such wide hulls, though there is some presumptive evidence in the performance of the Prout *SEA RANGER* and the Hedly Nicol trimaran hulls.

If now, we are intending to use a low aspect ratio keel, as described in A.Y.R.S. No. 59 *Multihull Design*, the depth of keel will be equal to the hull draft. However, except in very small boats, perhaps up to

24 feet in L.W.L. where the crew weight is important, ballast will be necessary to use this amount of buoyancy provided by such a hull section. This hull section will be quite familiar to everyone which is not surprising as we are unlikely to discover anything absolutely new in our argument.

The Hull Profile. This hull profile gives the low aspect ratio keel as described in A.Y.R.S. No. 59 which is again more or less traditional for shallow draft centreboard yachts. Because the lateral resistance could be rather far forward, a skeg should be used aft to balance this and bring the rig aft. It is perhaps noteworthy that the latest Sparkman & Stevens designs have a very similar shape, though they hang more ballast lower down, thus producing a concavity in the keel line forward.

The Single Hull Design. If this hull were to be used as a single hull, some ballast would be needed to take her down to her marks in any of the large sizes. Even though the heeling force on the keel would be less than with the usual deeper keel, the yacht would be very tender and would need a two masted rig, for instance Wishbone Ketch or ordinary ketch, or even a "Brig Rig" with two semi-elliptical sails. The sail area would have to be kept small.

The Multihull Design. This hull would not be totally satisfactory for a multihull because the displacement would be too great. By narrowing the hull beam, however, it could be made to work well.

Dear Mr. Morwood,

Regarding your proposed article, "The Most Efficient Yacht," I would suggest a revision which avoided the term "efficiency." Efficiency, to the engineering fraternity, can only mean the ratio of the output *power* to the input *power*. Possibly a term such as "figure of merit" could be applied to the characteristics your article mentions.

As to the optimum length-to-beam ratio, my article in A.Y.R.S. No. 45 indicates in Fig. 2 that 8 may be an optimum ratio when equal lengths are compared. However, Fig. 3 indicates that the best ratio is 16 or higher when comparing equal weights without a length restriction. Fig. 8 considers the effect of reducing the draft compared with the semi-circular section.

Your discussion of stability did not include the possibility of the non-heeling foil of A.Y.R.S. No. 51. To me, this has been one of the most exciting developments in a life-time of sailing. I do not know why it has not caught on. However, it should not be ruined by a poor sail area to weight ratio. The principal merit of the scheme is the large sail area it permits with stability for a given weight.

This past summer, I equipped an 80-pound canoe, 18 feet long, with a single non-heeling foil, on an outrigger, and 150 square feet of sail. The resulting total weight of 287 pounds, including a one-man crew, gave $\frac{\sqrt[2]{As}}{\sqrt[3]{W}} = 1.85$. This is a very high non-dimensional sail-weight ratio. This craft not only pointed high but had the greatest acceleration, without heel, in strong puffs of wind, that I have ever experienced. It scared me! This is a boat for a younger man than I am.

I would strongly recommend an ample rudder so as not to have a stalled rudder from over-powering by the sail. This is especially true in running where one cannot slow down because one cannot luff. Also, the forward half of the canoe should have a canvas cover to prevent swamping in waves.

Sincerely,

EDMOND BRUCE.

Lewis Cove, Hance Road, Fair Haven, New Jersey, U.S.A., 07701.

Dear Sir,

On page 76 of A.Y.R.S. No. 56, Bruce M. Larrabee writes that he has never found in any book the (forward) pressures developed on each square foot of sail area.

The following, (adapted ex Morwood's book, *Sailing Aerodynamics*), may show the information exists and can be turned up with a minimum of effort.

Given that we are to consider beam wind free sailing cases only.

Given that the Coefficient of Aerodynamics Force = 1, which is near enough when sailing free and with the usual sail.

Given that P = Aerodynamic Force in lbs. per square foot of sail.

Given that V = wind velocity in feet per second.

Then $P = 1 \times V^2 \times$ constant.

Note that when V = 5 ft. per second the constant is .0010,
and when V = 8.5 ft. per second the constant is .0012,
and when V = 25 ft. per second the constant is .0013,
and when V = 33.8 ft. per second the constant is .0014.

The wind velocity when it strikes the sail is of course the Apparent Wind velocity V_A. V_A exceeds the True Wind velocity V_T, except when the boat is stationary or travelling down wind.

Strictly speaking therefore we should substitute V_A for V in the above formula. However that would only give us initially the aerodynamic force P and not the forward thrust, which is a lesser component of P. The forward thrust would then have to be calculated as a second and rather tedious step towards the required result.

But for the rough-and-ready, there is an easier way. I call it the free-sailing-formula because it gives the approximate forward thrust in beam wind free sailing conditions only. It is as follows:

Let F = Forward thrust in lbs. per square foot of sail.

Let V_T = True wind velocity in feet per second.

Then $F = V_T^2 \times$ the constant previously given.

Mr. Larrabee (p. 76) gives three experimentally obtained values for F, namely .1, .8 and .7 lbs. per sq. ft. of sail; and by using these in the free-sailing-formula we find that they occur when the True wind has velocity 9.13, 25 and 23.7 feet per second.

We can now expand Larrabee's tabulation on page 76 as follows: and the results seem probable. (Note in close hauled sailing, Vmg = the rather complicated boat speed made good towards the windward mark; but when sailing free, Vmg = boat speed made good in the direction the bow is pointing).

When sailing free, Boat Speed = Vmg. M.P.H. or feet per sec.	Forward Thrust, F lbs. per sq. ft.	Velocity of True Wind V_T M.P.H. pr feet per sec.	$\frac{Vmg}{V_T}$ Ratio	Remarks 14′ Jet Dinghy, with crew: assumed sailing free:
4 or 5.87	.1	6.22 or 9.13	.643	in smooth water:
10 or 14.67	.8	17.04 or 25	.587	in smooth water:
12 or 17.60	.7	16.16 or 23.7	.743	in smooth water, planing.

G. H. Gandy.

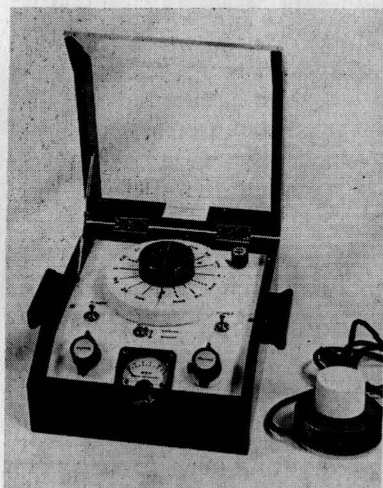
King's Grange, Castle Douglas, near Dumfries.

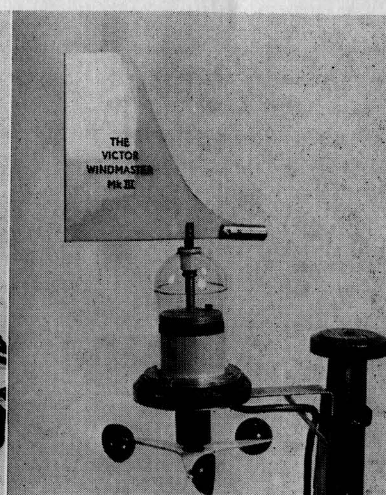
WINDMASTER Mk. II

Victor Navigation Co.

11, Hawthorne Drive, Salford 6, Lancs., England

The instrument is described as a Navigational aid for giving the wind's direction, the vessel's course and the sailing angle. It consists of a wind vane for mounting at mast head and wired to a portable console on deck or below. The latter consists of a small yacht's compass mounted in the centre of a translucent rotatable dial beneath which are mounted 16 torch bulbs at intervals of 11¼°. Each bulb is focussed to give a spot of light on the dial. The vane unit turns a rotating switch arm which passes over 16 contact studs each connected to a light bulb via a cable from the masthead. The direction of the apparent wind is thus shown, when sailing, by the relation of the light spot to the dial and to the compass. A rotary switch can be set to sound an alarm buzzer or bell at any one of the bulb position, so that the alarm will sound if the wind direction shifts from the selected position, to the nearest point or 11¼°.





In the model sent for test the vane gear is protected against the weather but some rain was found inside the unit after exposure. The vane itself weighed 4 oz. and the complete vane unit 2¾ lb. without the fixing bracket. The vane is adjustable for sensitivity but on the model tested the vane would not respond to winds below 8 knots. A cross arm type of vane is available which would be more responsive for light weather.

The vane is also dynamically damped by means of a "flywheel" mounted on the vane shaft.

The current consumption of the instrument on 6 volts is 0.4 amps. The receiver is strongly made and has a smart appearance. The plugs and sockets are of the radio type and require reasonable protection against rain and salt water.

In operation, the alarm bell sounds as intended and with practice it would seem possible to sail "on and off" the alarm which would reduce the variation to something less than 11¼°. The Windmaster would be valuable to a helmsman in keeping a sailing course, particularly at night.

The instrument would be less suitable for performance measurement since the indication of the wind angle is not sufficiently fine for this purpose.

A feature of the instrument is its simplicity and ease of maintenance, which might involve the occasional replacement of the torch bulbs as required. A dimmer resistance can be adjusted to give the minimum light necessary, so prolonging the bulb life.

JOHN HOGG.

THE INVENTOR'S ART

BY

JOHN MORWOOD

This article was written in 1956 but is of more interest now than then.

All yachtsmen are inventors. They have to be. Every time we sail our boats, we must learn something new and most of these new things come to us as a result of our experience and not because we have been taught them. We experiment with a sheet lead. We try a new sail. Somethings breaks and we have to fix up a jury rig to get us back to port. All these things need invention. But these simple matters are not what most of us regard as "Invention."

Invention to us has come to mean a more or less radical transformation of a device with the idea of improving the work done for a given amount of energy absorbed. For yachts, it can be expressed in the form of changes in either the underwater or above water structure which allow the same wind energy to drive the yacht's crew and their personal belongings along at a greater speed *or* it may mean that changes in the equipment allow the crew to drive the yacht with less work.

There are two kinds of Invention:

1. Development Invention.
2. Scientific Invention.

Development Invention. Three different lines of developmental invention have been published by the A.Y.R.S. They were on *Sail Evolution, Captain Illingworth's Development of the Fore Triangle* and *Outrigger Evolution.* In each of these, the starting point was a traditional device which was changed by small amounts in several or many stages to produce something which was quite different. Each stage, large or small, was an invention i.e., it was a trial of something different to see if it would be an improvement. The mental concept which produced the "Something different" was the invention. In developmental invention, for every trial which is an improvement, there are many more trials which are failures, perhaps in the proportion of a thousand failures to one success.

Scientific Invention. This method of invention has three important differences from developmental invention. These are:

1. A careful record is kept of all trials so that unsuccessful tests will not be repeated.

2. Systematic trials of all variants of an idea are made in turn, though most of them will obviously be failures from the start. For instance, sails of all aspect ratios must be studied to find out not only which is best but also to find out the basic principles of aspect ratio.

3. In the case of large and expensive things like aeroplanes and ships, a good many of the trials can be made on models. Wind tunnels and test tanks have been developed to study models with a precision not possible with a full sized version.

Scientific invention is to be desired if we are to produce worthwhile results quickly and at small expense. It is, of course, one of the primary functions of the A.Y.R.S. to record yacht experiments which are failures to prevent them from being repeated. Everyone hears of the successful trials soon enough. We may thus prevent all the usual yachting red herrings, Venetian blind sails, jibs placed here and there and the rest.

The second line of scientific experiment, viz., that of exploring every aspect of a new idea, can be seen in our Editorial policy with regard to Outrigger craft. With these, though the Prouts have shown that the double hulled craft is fast, safe and excellent, it is felt that the possibility of developing successful Indonesian or Micronesian craft should not be ignored and the development of both these types is being studied and will be kept before you till it is felt that they have reached the highest stage of their development to which modern knowledge and materials can take them.

The third line of scientific development is to be found in testing models. This is done to save expense and to find out faults quickly because a model is more quickly made. It is an essential method for all scientific study. The A.Y.R.S. has a wind tunnel which is small and only suitable for testing model sails with a 7 foot mast but it is available for any sail tests which anyone wants to carry out.

The A.Y.R.S. finances do not run to a tank for testing model ship hulls but several methods for such tests have been developed which could well be used by our yacht designing members. Models may be tested by the very simple method of sailing them on a pond against other similar types. John Hoggs and Col. Bowden's method for radio controlling sailing yachts would be a great help in tests of this kind. Finally, it is possible to study the behaviour of craft by towing them from the side of a pond by two strings tied to the forestay and backstay at the height of the estimated centre of effort of the sails.

"*Over Invention.*" This is a common fault of which the inventor should be careful. Few men of an inventive turn of mind have only produced one invention in their lives. Mostly, they have had a long inventive career. Among what if often a very long list, there are probably about half a dozen ideas which could be worth trying. However, let it be understood that the chances of any one of us producing even *one* idea which is going to benefit yachtsmen is extremely remote. Most of our ideas will be failures. Even if we put only two of our ideas on the same craft for a try-out, therefore, we may fail to recognise the merit in a good idea because of the failure of the whole machine. What is more important, we may get discouraged and stop experimenting altogether and so miss a chance of discovering something later on. Perhaps the long intervals in between developments which occurred with both Captain Illingworth and Roland Prout are examples of this discouragement. Both went on to fulfil and complete their ideas but we might not be so determined.

Financial Reward. I have never known anyone who has ever made any worth while sum of money out of an invention for sailing boats. In any case, it often takes sixteen years, the life of a patent, for a new idea to catch on. A case to keep in mind is the invention of the "bending boom" by Manfred Curry back in the 1920's. This was promptly banned by the rule makers but is now allowed.

Summary. To invent successfully, it is necessary:

1. To read, ask or otherwise find out if something similar has been done before.

2. To consider only *one* modification to an already satisfactory design at any one time.

3. To make a model of the device and test it in every conceivable way.

4. To try out the full sized mechanism.

5. Not to be disappointed if the device fails. If it has merit, try again. If it has none, either give up experimenting or try another line altogether.

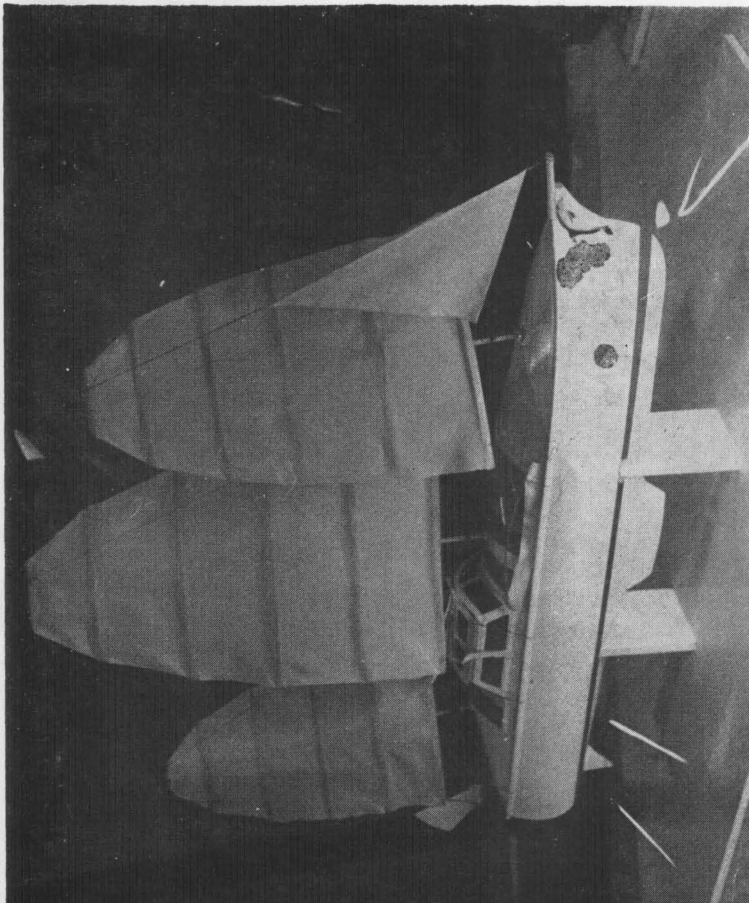
6. Not to expect to make money from an invention. I do not believe that it worth taking out a patent of any device for sails, sail sheeting or aerofoils. Patents cost a lot of money. On the other hand, if one has invented a machine like a winch, or motor or electronic device *and* has the backing of a firm to make it for you, it is probably worth patenting.

PELORUS JACK II

The photograph shows my model for the 1965 *Cruising Yacht Design Competition.* I tried to race it without outriggers in the form which is shown and she was overpowered in the strong wind. She was stolen later and I doubt if I shall make the type again. However, there were some interesting features so a paragraph on her may interest someone.

The hull which had 6 inches of beam and 36 inches L.O.A., was made from developed plywood. The line of discontinuity between the front conical part and the after "cylindrical development" can be seen as a shadow. The deck is not part of this and was added separately. The cockpit, which was self-draining and covered by lifting doors was designed for maximum weather proofing. The full "Ship" rig with three semi-elliptical sails which could be dropped down their masts for reefing and furling are most clearly shown.

Perhaps, this model was an example of "Over-invention" but it was a lot of fun to make.



PELORUS JACK II

A SPOILER OF SPEED

BY

LT. COLONEL C. E. BOWDEN, A.I.MECH.E., C.R.AE.S.

A study of some of the causes, effects and control of excessive pitching —sails, boat and helmsman can suffer severe handicaps.

By courtesy of the Editor Yachts and Yachting

The problem of excessive pitching and its control although affecting all racing yachts, particularly concerns Twelve Metre development in connection with any future challenge for the "America's" Cup. The 1964 Cup series of races highlighted the phenomenon of pitching, and the resulting serious loss in "speed made good to windward," or V/mg in research terms.

If we study the 1964 Cup series, it will be found that the Twelve Metre with its tall rig and relatively narrow hull is highly instructive through exaggeration of forces and principles. Therefore its development is of particular value for all keel yachts that race around the buoys, for what occurs on a Twelve Metre will happen in general principle on smaller displacement keel boats.

It is worth recalling the tip given by Rod Stephens, with his experience in the cockpit of *CONSTELLATION* still fresh in his mind, during his lecture in this country after the Cup races. This was to the effect that the Americans realised that small boat and big boat racing techniques (such as the control of sail curvatures by using the small boat flexy mast and boom and other sailing methods) are fundamentally the same with suitable modifications.

This study therefore looks at the problem of the control of pitching and "speed made good to windward" (V/mg) from the wide range of the Twelve Metre at the top of the size scale, down to the X One Design keel boat.

Many considered that during the British trial races off the Nab Tower, and the subsequent Cup series in America, a major defect of both the challenger *SOVEREIGN* and *KURREWA V* was excessive pitching in a seaway which reduced their windward potential. Measurements in fact did show a lack of consistent close angular sailing to windward in a difficult sea. On the other hand, *CONSTELLATION* the American winner by such a large margin in each race, sailed with great consistency through difficult seas, at angles to the apparent wind as fine as 20 degrees, and even finer in useful wind gusts. This was done at noticeably smaller angles of heel. There was little throwing of water forward from the bows, which were slicing the waves and parting the water sideways. *CONSTELLATION*'s pitching and angle of heel were in complete control with a very consistent high V/mg (Photo 1).

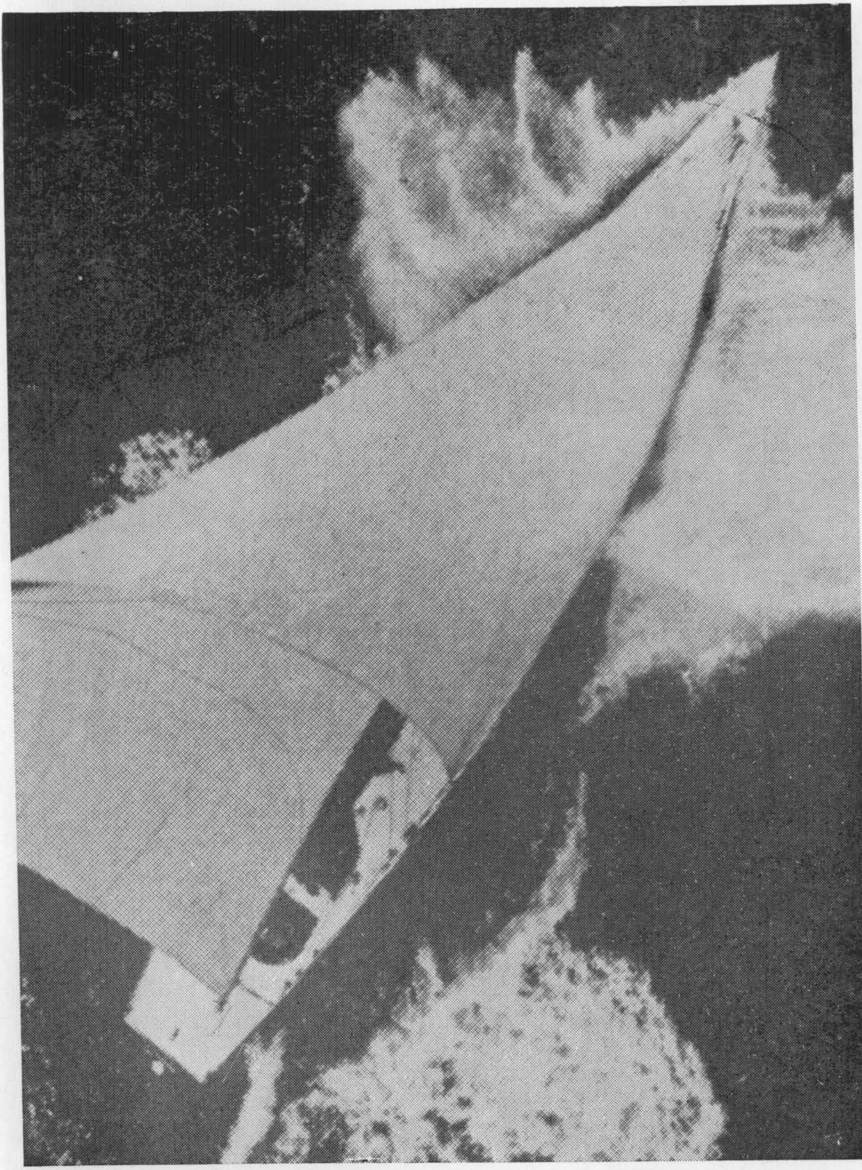
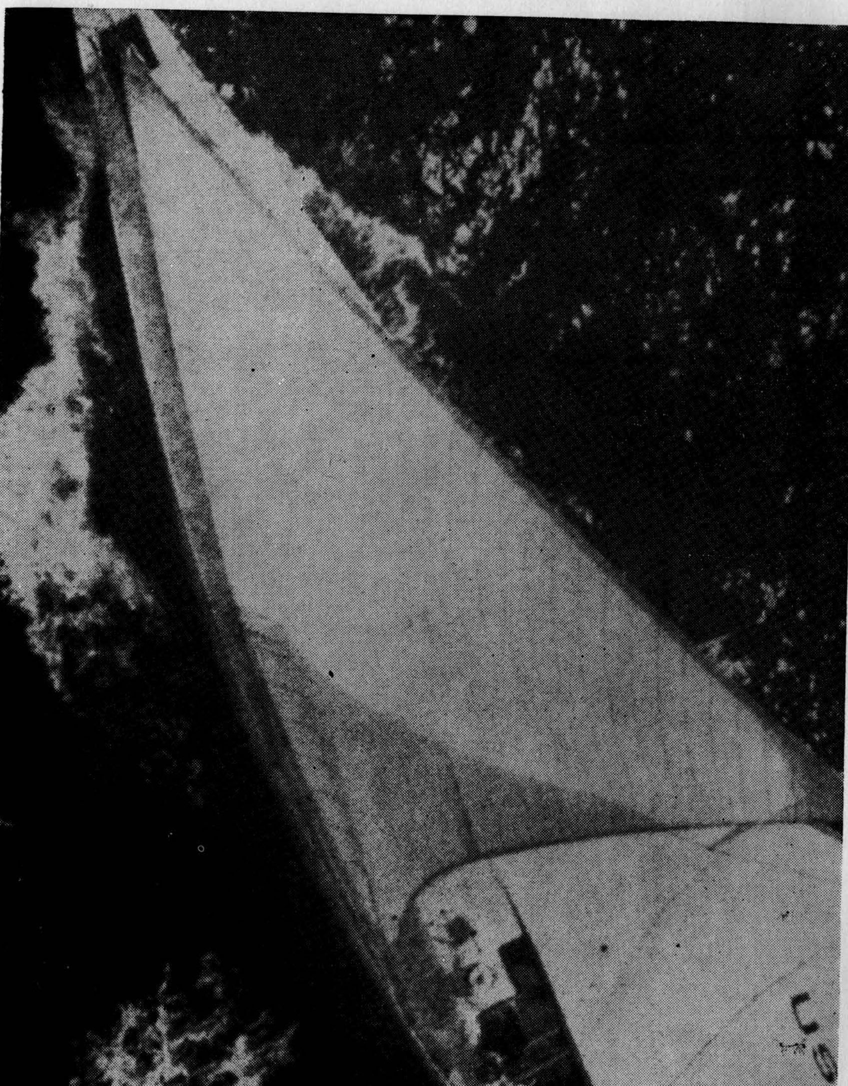


Photo 1. *These shots were taken of SOVEREIGN and CONSTELLATION* (*Page* 74) *during the* 1964 *"America's" Cup Challenge. SOVEREIGN is shown to be pitching severely. Her bows have just slammed down—note how the spray is thrown clear roughly normal to the hull when*



viewed in plan. The counter is well raised and the quarter wave has travelled forward. CONSTELLATION appears to be making much easier going of the same conditions. Her better pitching characteristics and small angle of heel give her a chance of putting up a superior performance to windward.

One American ciné film of the trials racing and Cup Series in America emphasised that *SOVEREIGN* sailed on average at a greater angle of heel, and at a coarser angle to the wind when pitching in difficult seas. This film also showed a revealing "close up" of *SOVEREIGN* in a particularly bad pitching paroxysm falling away to leeward at a poor angle to the wind. The sails were feathering ineffectually aloft due to masthead whip back and forth, the water was being flung forwards from the bows and even backwards from the counter as the hull see-sawed with a yawing corkscrew motion. *CONSTELLATION* could be seen sailing well out to windward without apparent fuss at a low angle of heel.

During the Nab trials period—when I was connected with *KURREWA*—records of the trial boats showed excess heeling, sometines at angles of around 30 degrees in a fresh breeze or a squall. These angles of heel create acute pitching problems (Photo 2).

A great deal has correctly been written and said about how angle of heel should be controlled on all keel boats for reasons connected with hull resistance and keel efficiency in windward sailing. But how well is it appreciated and acted upon in yacht development and research work., that excess angle of heel excites a yawing rotational pitching movement in a difficult seaway which completely wrecks constant sail drive, close angular sailing and effective keel operation in windward sailing? On the other hand the careful control of angle of heel within certain defined bands can reduce pitching. In other words the control of angle of heel has a double pay off when seeking exceptional "speed made good to windward."

It has been considered that the two British trials hulls were overlively in pitch, which is undoubtedly true and in itself this can cause a sensitivity to pitching. In my estimation there were also other important factors from all the evidence available including an overriding angle of heel fault that seriously increased the pitching trouble. Agreed this is only my personal view, but I think it should be carefully examined. It has also been considered that the British hulls were a little stiffer than *CONSTELLATION* and yet they sailed at a greater angle of heel.

A pitching hull requires more than twice the horsepower to drive it through waves, whilst at the same time excessive pitching makes it impossible for a helmsman to keep his sails at a reasonably constant angle of attack to the wind to provide a steady drive through the seas. The total result is an unacceptable loss of the vital speed made to windward (V/mg) as demonstrated so dramatically by the 1964 Cup series. This affects all keel boats racing round the buoys.

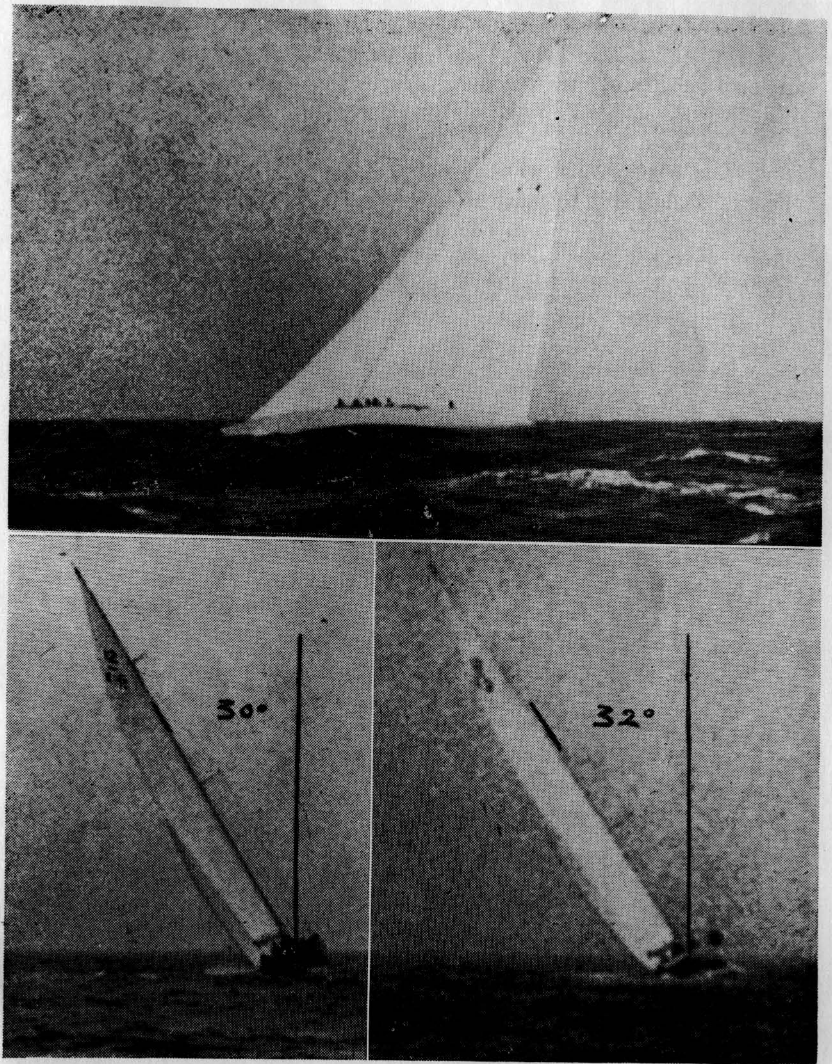


Photo 2. Once a yacht hull begins to sail at an angle of heel greater than 20 *degrees, (approx.), then V/mg begins to deteriorate very rapidly. The photograph shows SOVEREIGN (left) and KURREWA V (right) sailing at an angle of* 30 *degrees and* 32 *degrees respectively. Once a yacht is sailing at a steep angle of heel it becomes impossible to curb pitching tendencies. Above is KURREWA V sailing at a marked angle of heel during the Nab trials.*

Pitch Relative to Heel

An over simplified but nevetheless useful starting point from which to develop the reasons for pitching and its control can be demonstrated by the old fashioned rocking chair. If you wish to rock you push the fore end of the chair upwards, as an oncoming wave does to the bows of a yacht, with the occupant of the chair acting as a central keel weight or pivot. At the same time you ensure that there is no damping or restricting matter between the after rockers and the floor to resist the rocking motion. When you want to stop the rocking action you check the rocker arms at the rear of the oscillation to resist the motion, which is akin to stern damping aided by the increased buoyancy of an asymmetrical hull and its stern coming into action. The fundamental problem resolves itself to reducing the bow action, and damping out the remains of the pitch. There is however an additional factor which introduces a rotating yawing motion to the bows, which I have not seen discussed in detail before. This is the degree of the angle of heel at which the yacht is sailed to windward and its rotating effect on the bows.

An excessive angle of heel can make an over-lively hull pitch heavily in a difficult seaway for its length. It can also make a well damped hull into a bad pitcher with a poor V/mg as can be shown in One Design racing. Furthermore, the excessive yawing, twisting or rotational rise of the bows, and the accompanying depression of the stern to leeward in a rotary motion aft, caused by sailing at too great an angle of heel, introduces a whole chain of quite vital side effects on the angle of attack of the sails keel and hull, which can be explained in a perfectly logical sequence.

Similarly, the control of heel angle, within certain defined bands, can be made to control pitching and provide the necessary constant drive from the sails at a fine angle to all useful wind gusts to obtain a consistent optimum V/mg which is the major factor that wins races.

When this fundamental reason for the yawing-rotary-pitching action became clear to me as being largely due to the angle of heel at which the boat sailed in certain seas difficult to the length of the hull, I found that it was quite possible to induce purposely a yawing pitch, which could be measured by recorder and also felt on the helm. This led to a more detailed investigation of V/mg measurements on the X.O.D. assisted by an electrical recorder and also on a large radio controlled 1/9th scale Twelve Metre model—7 ft. 6 in. long with rig approximately 8 ft. 6 in. tall. The conclusions I reach in this article are based in a number of cases upon the windward performance measurements of several different Class Racing Yachts, made by a friend John Hogg and myself during our work on yacht research. His multi-pen-recorder has provided considerable supporting information in regard to the ingredients that go to make up Optimum Speed made good to windward, or Vmg.

Similar Hulls can vary in Pitch Characteristics

Racing experience has repeatedly brought to notice in our "X" One Design Class, in which all hulls are the same shape and weight with the same pitch frequency, that a few boats will sail to windward closer and pitch less than the rest, and at the same time sail at a lower angle of heel in a certain type of sea difficult to their length.

It has often happened that within 200 yards or so, one or maybe perhaps two or three boats have drawn ahead, sailing closer to the wind at an obviously lower angle of heel and pitching considerably less than the rest of the fleet until the leaders arrive at the windward mark maybe over a quarter of a mile ahead of the back markers. This is a remarkable difference in speed made good to windward for a One design fleet with such similar basic performance that it can normally be expected to arrive very close together in less difficult seas.

Since all hulls are the same, it is obvious that there is something outside hull shape and pitch frequency that is causing this noteworthy difference in pitching and its effect upon V/mg. The answer is that the leaders are working the rhythm of the difficult seas at a more controlled angle of heel. This reduces their pitching and enables them to sail faster and closer to the wind. How they achieve this opens up a wide and intriguing range of factors connected with the vital control of heel angle which is drastically affecting their V/mg in a seaway. These factors come roughly under the following headings: (a) How angle of heel affects pitching. (b) How angle of heel affects V/mg, through sail curvatures, through angle of attack of the sails and through angle of attack of the keel. (c) What produces optimum V/mg measurements in different wind speeds. (d) How to reduce angle of heel to the required stability compromise within the necessary pitching control bands. (e) How an asymmetrical hull and its "wider" stern affects the control of pitching. For convenience sake the last item is taken first, because most new designs and all modern "America's" Cup hulls are now of asymmertical form.

The Asymmetrical Hull and Pitch Damping at Moderate Angles of Heel

Some years ago I found with large radio controlled free sailing models and a little recorder showing pitch and heel, etc., that a truly symmetrical hull, with both ends nearly the same and maximum beam amidships, was inclined to pitch more than a well designed asymmetrical hull. The details were published by the Advisory Committee for Yacht Research in 1960.

The asymmetrical hull has a long lean bow with the maximum beam aft of amidships and a "wider" stern designed to fit into the wave

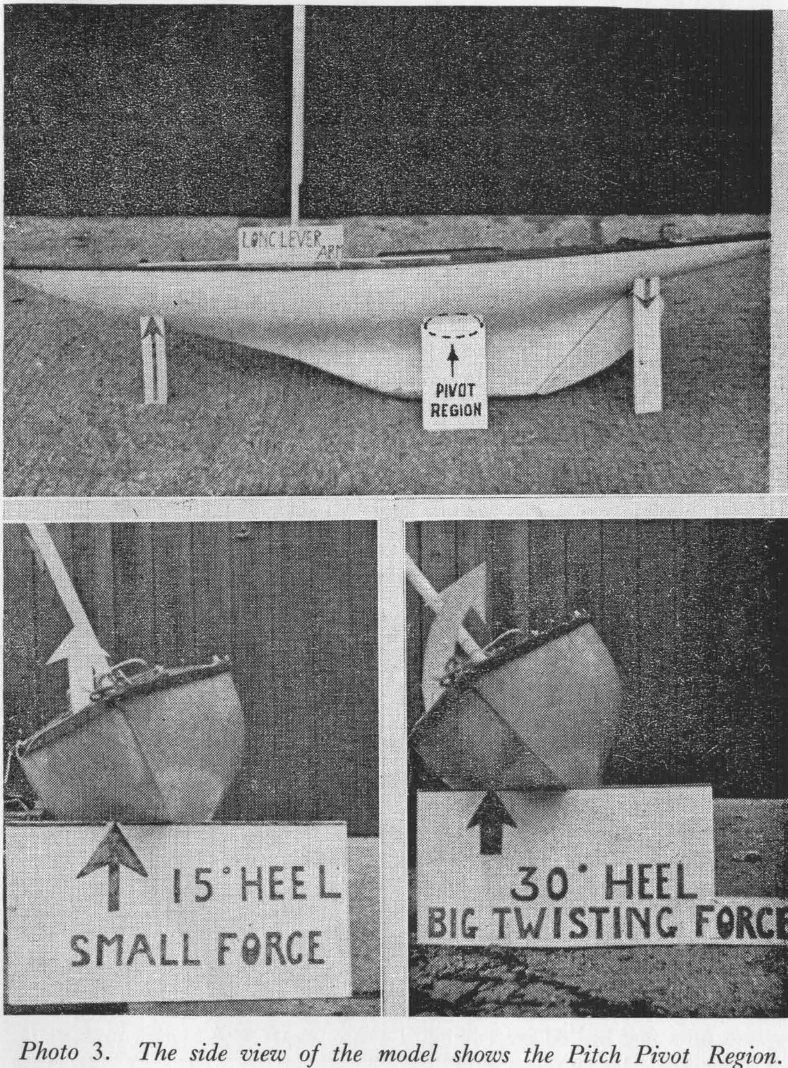


Photo 3. The side view of the model shows the Pitch Pivot Region. The view (lower left) indicates the relatively small reaction of a wave against the bow when the angle of heel is small. When the hull meets a wave at a low angle of heel, the upward and sideways reaction is small. On the right the hull is heeled to 30 degrees, and the large curved arrow indicates that when the lee bow is on its side, it is driven upwards with considerable force by the strong reaction between the waves and the "flat" surface. The bows are also swung to windward which changes the angle of attack of both keel and sails.

pattern of the yacht when sailing to windward at a moderate angle of heel. The more buoyant sections aft with the wider stern damp out a lot of pitch. Later research found that the asymmetrical hull shape should be sailed at a moderate angle of heel within very close bands for varying wind speeds, to cope with pitch damping and achieve its speed potential. Thus when the hull is sailed at a low angle of heel consistent with stability requirements the long lean bows slice and part the waves as designed. However, when the same hull shape is over-heeled it will happen that the long lean bow sections are laid on one side and react to an on-coming heavy wave into a yawing upward pitch action with which the damping powers of the asymmetrical hull cannot cope. The final result is that over-heeling and excessive pitching can produce a notably slow boat from a potentially fast shape when properly slicing the waves in an "upright" position. These broad statements require to be examined in more detail.

A yacht can sail to windward at a considerable angle of heel in smooth water without any noticeable adverse effect on pitching—a recorder will show this—but the windward performance in terms of V/mg will suffer from extra hull resistance, loss of keel efficiency etc. These facts can be accepted without pursuing the matter further. However, to sail the same yacht over-heeled in a difficult seaway for its length, will add to these well known adverse factors so that a completely unacceptable further loss of V/mg efficiency is produced through heavy pitching which affects both sail and keel angle of attack for the following reasons:

Waves, with a few exceptions come from the same direction as the "true wind" when a yacht is sailing to windward. A yacht's forward speed creates a "Relative Wave Angle" on the same principle in which a relative or "apparent wind angle" is created from the wider angle of the true wind. The visual waves appear to be advancing along the true wind path, but the faster the yacht sails to windward the more ahead the relative wave angle is in fact attacking the bows. Fig. 1. This point has to be remembered when visualising the ahead effect of waves on a fast hulled craft like a Twelve Metre. A slower craft sails at a coarser relative wave angle.

In exceptionally heavy seas when pointing becomes difficult and V/mg must inevitably suffer, the yacht has to be sailed slightly freer, more along the waves at a coarser angle to the wind. Unfortunately, the extra speed through the water is usually insufficient to make up for close angular sailing, and sailing free becomes the last ditch method usually forced upon short length keel boats as an inevitable evil. It is unlikely to pay off against a *CONSTELLATION*.

FIG. 1.

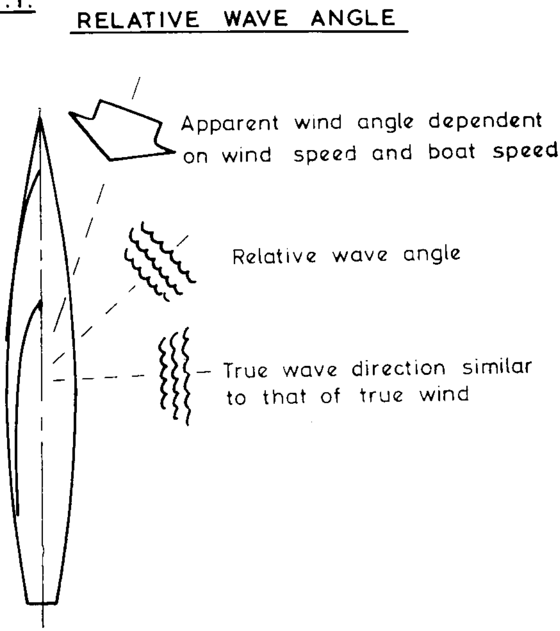


Fig. 1. As a yacht gathers way, the apparent wind swings forward. Usually the line of approach of the wave system follows a path similar to that of the true wind. It follows, therefore, that the yacht's speed through the water will create an "Apparent Wave Angle."

If a long, lean asymmetrical Twelve Metre hull is visualised, it will be clear that the hull's mean "pitching pivot region" will be somewhere around the static centre of buoyancy when floating in flatwater at given angles of heel. As the hull moves through a wave system its centre of gravity remains at a fixed point (somewhere just above the ballast keel as a rule). The centre of buoyancey, however, will shift considerably because the changing wave form will immerse different parts of the hull, Fig. 2. It is the couple generated between the c.g. of the complete yacht and shifting c.b. which encourages a yacht to return to her normal static trim. There is a long lever arm from the advancing bows that encounters the incoming wave, to the "pitching pivot region." Shorter boats have a smaller leverage but the general principle is the same. Aft of the pitching pivot region are situated the damping widening buoyancy sections followed by a moderately "wide" stern. As remarked earlier, the stern of a modern asymmetrical hull is designed to fit into the wave pattern of the hull sailing to windward and heeled to a moderate degree only, to suit the optimum V/mg sailing.

FIG. 2.

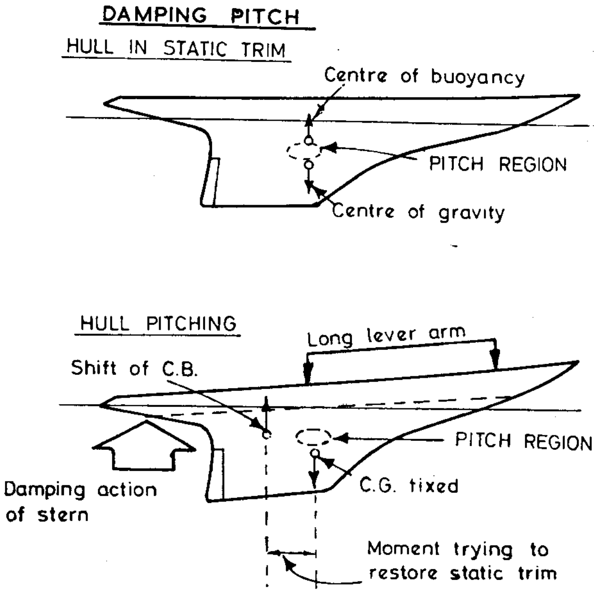


Fig. 2. Once wave height and period reach certain proportions—these vary from yacht to yacht—a hull will be induced to pitch. When a yacht is floating in normal static trim, the lift of the centre of buoyancy is directly above the c.g. of the complete hull through which acts the all-up weight. The c.g. remains fixed, but the c.b. will vary in position as different parts of the hull are immersed. A pitching couple is generated each time the c.b. shifts away from the direct line of action of the force acting through the c.g. The shift of c.b. varies so there will be a corresponding variation in the point about which the hull pitches. For all practical purposes, the centre point of each pitch will be within a small region somewhere just above the position of the c.g.

The advancing bows rise to an oncoming wave, the height of rise and the extent of the yawing twist to windward being greater as the heel angle increases for reasons stated below. The stern tries to twist to leeward as it goes down whilst the bows rise and rotate to windward. The speed of the boat naturally reduces this twisting movement through dynamic damping, Fig. 3.

When the yacht is sailed to windward at a low angle of heel (Fig. 3, and photograph 3) the long lean bow sections slice the waves as designed in a near vertical attitude, throwing the parted water sideways,

FIG. 3.

PITCH INDUCED OR CONTROLLED BY ANGLE OF HEEL

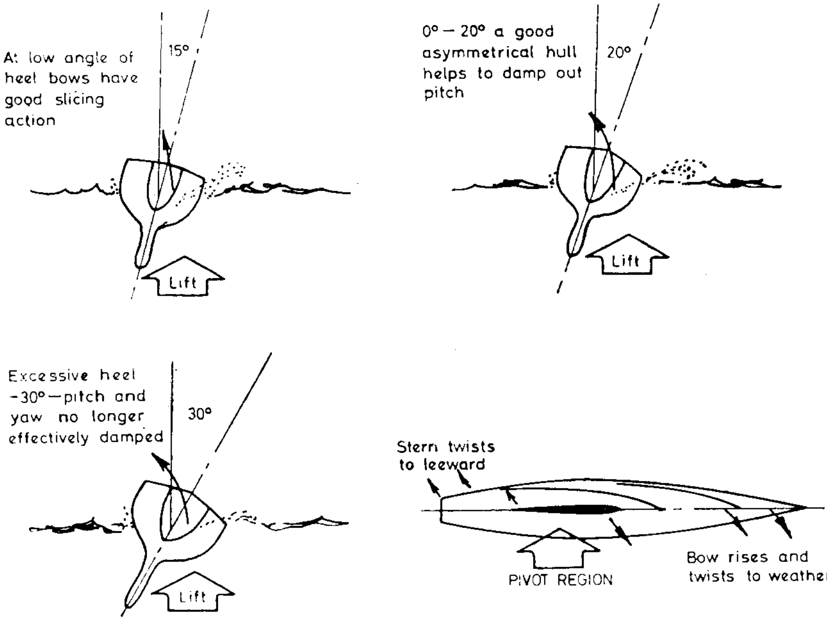


Fig. 3. *Up to an angle of heel of about* 15 *degrees, the forward end of a racing yacht hull has a good slicing action and there is little variation in angle of attack of keel and sails. As the angle of heel increases so does the tendency for the hull to pitch and throw its bows to windward. From* 0-20 *degrees an asymmetrical hull helps to damp out pitching but above this angle of heel no yacht hull can effectively suppress pitch.*

as seen in Photo 1. The bows are, therefore, only subjected to a relatively small upward force from the waves and little side reaction.

If the bow sections are slightly U'd with near vertical sides there is less angular resistance offered to the waves for a twisting action than when a more V'd flared bow is used, the latter being more prone to create an over-lively hull. Fig. 4. This point can have a noticeable effect in reducing troubles with a sail and keel angle of attack.

When the yacht is sailed at a large angle of heel (Fig. 3 and photograph 3) at over 20 degrees to 30 degrees and more, the lean bow sections are attacking the "relative waves" with their sections largely laid on one side. This forms a long "flat planing surfboard" surface advancing at an "ideal" angle of attack for the wave's force to drive the surface upwards and sideways into a rotating yawing path towards the wind. The severity of this yawing pitch is naturally aggravated in a long Twelve Metre by the length of the lever arm from the bows to the central "pitch pivot region," the effect being greater because of the "narrow" wedge-shaped hull.

It will be seen that angle of heel becomes an over-riding and basic factor that can either excite or control pitching, and drastically affect V/mg, for it is the rotational twisting path of the bows and stern that has very serious consequences upon sail and keel angle of attack efficiency, which is the final nail in the coffin of optimum V/mg.

The stern at a heavy angle of heel and during an extra large pitch is forced down and rotated so hard to leeward aft, that in an extreme case as the boat speed drops and hull pitch frequency gains a hold, it will actually dig in to leeward aft with excessive drag. If the boat is sailed at a low angle of heel, as it should be, the stern will achieve its proper function of damping out any slight pitching effects, for the

FIG.4.

BOW SECTIONS CAN HELP CONTROL PITCH

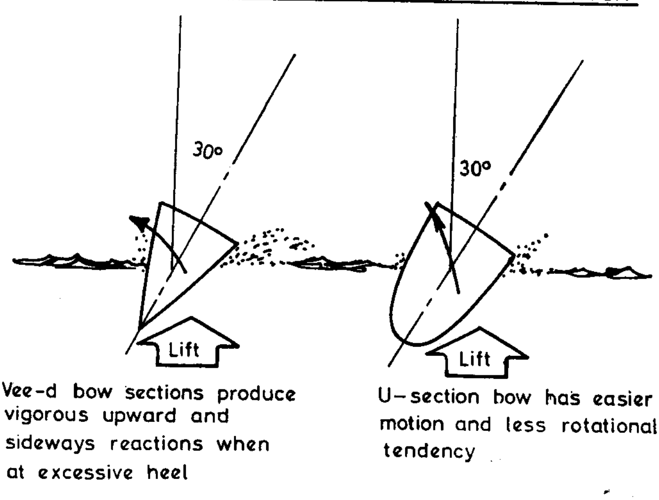


Fig. 4. The vee'd hull may have better wave-slicing properties when it is sailing at small angles of heel, but it is very lively and likely to slam at a marked degree of heel. U'd sections forward produce a motion which has less tendency to yaw the hull.

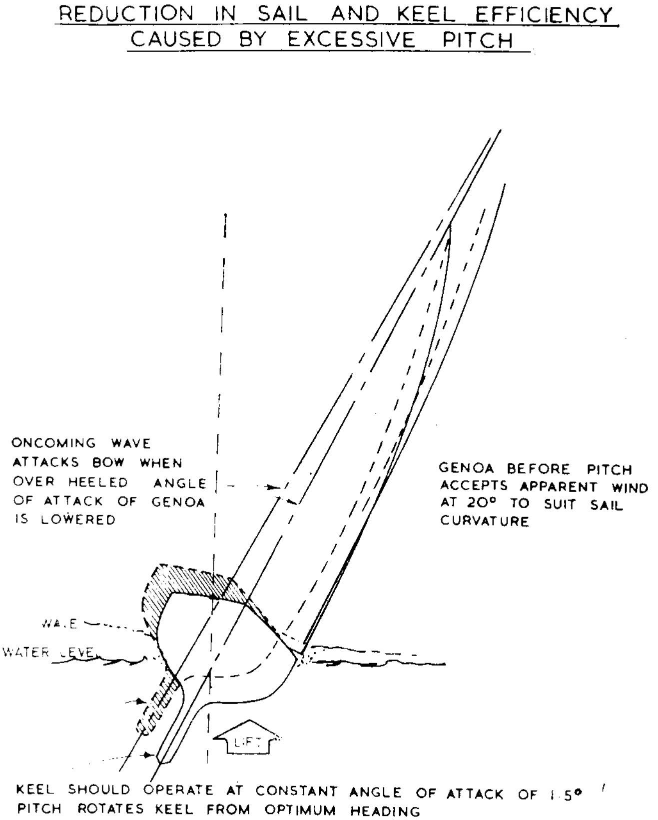


Fig. 5. A sail plan can only develop optimum lift while at a constant angle of attack for which it is correctly trimmed. Once the hull begins to yaw and pitch the angle of attack of both sail plan and keel may be drastically changed. Once the trim of the sail plan is disturbed, V/mg suffers accordingly.

stern now reaches out to leeward aft with a steadying "tail-plane" effect. The initial hull speed reduces all these actions, but as pitching builds up, the dynamic damping through boat speed dies and hull pitch resonance frequency can take over in the last stages of pitching.

Furthermore, (Fig. 5), as the bows rise and rotate to windward, and the stern twists to leeward, the hull streamline and hydrofoil keel surfaces are displaced from their effective forward travel heading and steady angle of attack into a rotational path, which upsets smooth waterflow and prevents them resisting the leeway slide which is their

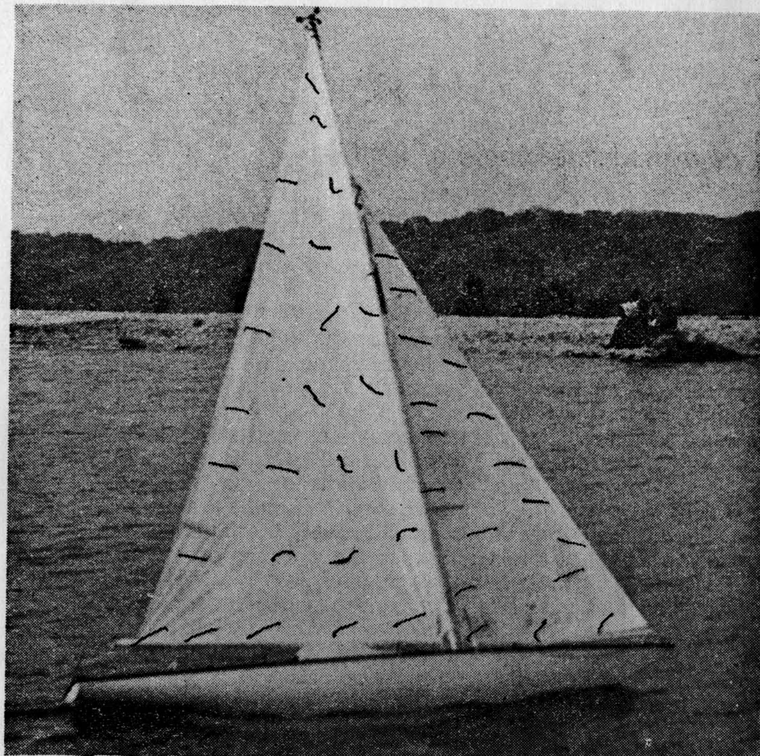


Photo 4. This 1/9th scale model of a Twelve Metre is radio controlled and is shown sailing here with wool tufted sails. The flow in the mainsail has been taken much too far forward and the wool tufts show the windward side of the sail in turbulent flow for almost half its chord. The spars fitted to this model are almost rigid. Note how the flow in the mainsail has been allowed to drift aloft leaving a flat foot to the sail. This characteristic alone will cause excessive heeling. Flexible spars will correct this fault. (Note: Wool has been touched in for clarity.)

designed function. The pressure differential between high pressure and low pressure of correct hydrofoil keel action is lost for the keel is no longer travelling consistently in windward sailing at an optimum 1½ degrees angle of attack in the case of a Twelve Metre or between 3 to 4½ degrees in the case of most smaller boats.

An examination of a model Twelve Metre hull laid on its side at varying angles of heel will demonstrate that an angle bteween 8 to 15 degrees will create little serious pitch reaction, but definite pitch excitation can be expected to commence at around 15 degrees, in-

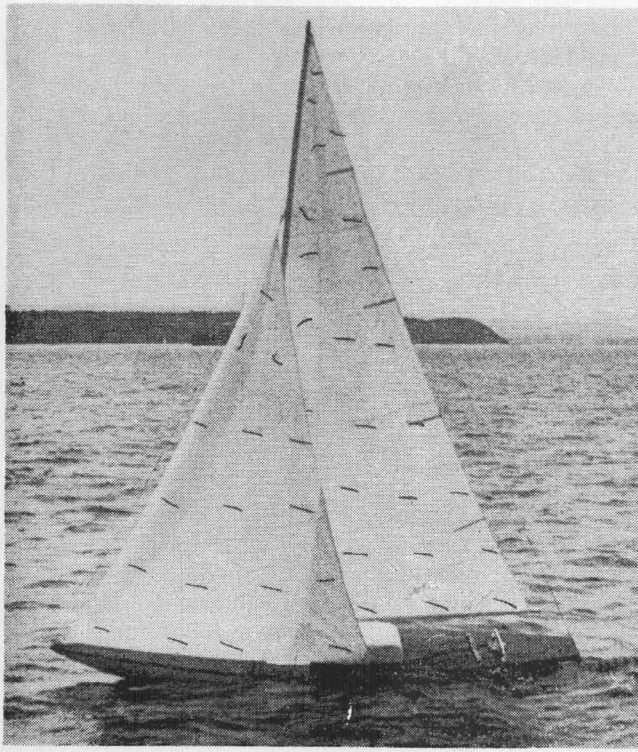


Photo 5. A photograph of the Twelve Metre model taken from leeward and showing the direction of airflow as indicated by tufts of wool. The pattern was actually checked at a later date against the performance of fullsize Twelve Metre sails. Note that the airflow over the lee side of the head of the mainsail is turbulent in the region where there is no slot created between genoa and mainsail. Although the turbulence at the head was relatively low when sailing at very close angles, the flow deteriorated as the boat sailed progressively broader courses. Behind the slot created by the presence of the genoa, airflow is smoothly attached to the lee of the mainsail.

creasing progressively in effect up to 20 degrees. However, a good asymmetrical hull shape and stern should be able to cope with effective damping up to around 20 degrees in a hard breeze. This has been proved in One Design racing. If the hull is allowed to heel from 25 to 30 degrees or over, pitching can be expected to get out of control. Our multi-pen recorder measured sailing tests on my X.O.D. which agree in general with these angles allowing for the faster and slimmer ratio of a 12 Metre.

A surprising and intriguing feature found during our V/mg measurement tests on the X.O.D. was that the yawing rotary movement caused by even very modest waves and pitch could be detected by the recorder pen trace of angle of heel, even in light winds, and waves so small that the helmsman was not aware of them on his rudder. It was possible with a little practice to obtain a very good idea of the height of these little waves through the extent of the pentrace of heel on the revolving chart.

From a study of Fig. 5 it will be noted that the upward and rotary path of the bows of a heavily heeled yacht, increased by stern twisting, upsets the all-important angle of attack of the sails for the essential constant drive required to obtain consistent optimum V/mg.

As the bows are thrown upwards and towards the wind, the leading edges of the sails are reduced in angle to the wind by several degrees according to the amount of pitch, thereby reducing power at the moment when most drive is required to punch the hull through the waves.

In Fig. 6 it will also be seen that an overheeled yacht pitching heavily, causes a rapid fore and aft motion to the head of a tall Twelve Metre rig, which has been calculated at Southampton University to be as much as 15 feet/second in bad cases. The same happens to a

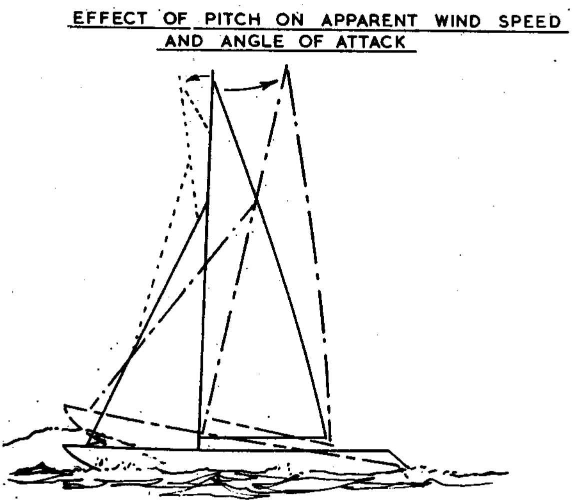


Fig. 6. When a yacht pitches in a seaway, the airspeed over the sail plan is subject to varying acceleration and deceleration. This, in turn, alters the angle of attack of the apparent wind so that the sail plan is incorrectly sheeted for much of the time during each pitch.

lesser degree to smaller yachts. This whip back and forth of the mast-head completely changes the "apparent wind" speed and also angle of attack of the sails during a bad pitch. There is also a rotary motion at the head away from the line of advance on the upward pitch and towards the line on the following plunge.

As the bows rise the masthead whips rapidly back reducing the apparent wind to nearly nil, and placing the head of the sails at a large angle of attack nearly to that of the true wind. The sail curvatures are not designed for this broad angle, nor are they sheeted for it. On the return whip the apparent wind is rapidly speeded up above the normal apparent wind speed. The wavy motion of the sails knocks out all pretence of fair airflow and constant pressure drive from the lee side. It also destroys the skill of the unfortunate helmsman in holding his sails at a reasonably constant angle of attack to the wind. A more centrally positioned mast as on *CONSTELLATION* reduces the wavy motion very considerably.

To put the matter briefly, it becomes impossible to obtain anything near optimum V/mg with an overheeled yacht pitching heavily in a seaway, versus one sailing at a controlled angle of heel and with pitching properly controlled in a more up and down plane which holds the sails at a constant angle of attack. The overheeled yacht has hull, keel and sails thrust efficiency all destroyed and the helmsman is defeated.

Factors that control angle of heel and create optimum V/mg

It can be assumed that the modern asymmetrical hull of suitable stiffness will be used as a basis for development. In order to reduce over-liveliness in pitch the hull will probably have its sharp bow sections slightly U'd, Fig. 1. The mast as on *CONSTELLATION* will aid suppression of over-liveliness if it is positioned as centrally as possible consistent with sail proportion to reduce pitching leverage and mast-head whip effect. A reasonably wide stern will be designed to be kindly in damping at a moderate heel angle, not too wide or too hard bilged. Weight in keel and elsewhere will be concentrated low, which in fact makes the hull more lively, but stiffer to keep heel low which is of greater importance.

There remain a number of factors concerning sails and helmsman technique which control heel, and pointing ability.

A flexy masthead will absorb excess gust shocks and also excess gust forces aloft by a measure of automatic "feathering" of the sails at their head to keep heel controlled. My own radio-controlled models have shown how considerable automatic heel control in heavy gusts and bad scale seas can be obtained by using a "feathering" flexy glassfibre fishing rod mast giving to excess pressure aloft. Such a model has always sailed closer to the wind in hard-scale weather and seas than a rigidly-braced model of exactly the same hull shape and sail area.

Tests have been carried out on my X.O.D. using an John Hogg's multi-pen recorder to discover just how V/mg is affected by alterations of course relative to the apparent wind and also angle of heel The recorder produces traces for apparent wind, its relative angle on the bow, heel, pitch and speed through the water.

All these ingredients for V/mg measurements have enabled performance curves to be made covering the whole range from sailing the boat "very close" to sailing "fast and free" provided the test run "samples" are kept short, sharp and crisp to get unclouded results. Optimum V/mg can then be found for different winds and conditions, and sail sheeting. The pen traces of heel and so on show what factors create optimum V/mg. Thus the boat, sails and helmsman, are "measured up" and any weak points in the chain are traced. Inconsistent sailing is also pin-pointed, and the reasons for it. I believe that any future challenger should be "measured up" by such a multi-pen recorder before practice racing begins, and as a final check that performance figures are adequate to make a challenge.

These tests have established in broad principle for the X.O.D. keel boat, that to obtain consistent optimum V/mg in light wind conditions (up to 10 knots), the emphasis is on close angular sailing with less emphasis on speed through the water. This is because a windward sailing keel boat quickly reaches about three-quarters its maximum speed through the water even at fairly low wind speeds. There-after an increasingly large force is required to reach the final quarter due to the boat's sharply rising hull resistance through wave making. At low wind speeds sufficient speed is easily obtained and all V/mg benefits must come from high pointing, but at high wind speeds greater drive is essential, and the course angle must be kept low by reducing heeling and leeway angles.

At the higher end of the wind speed scale it will be found that conventional soft sails lack drive. This points to the fact that there is still plenty of development work to be done in this field.

It can be shown that for each wind strength there is one optimum angle of heel and I suggest that this is a vital factor in any development work for the future "America's" Cup aspirant.

The best V/mg on the X.O.D. is usually achieved by pointing very high (and I mean very high) in light winds up to around 10 knots. A slight sheeting outwards is advantageous near the 10 knots wind speed. At winds above 10 knots, the best V/mg is found by pointing slightly less high with the boom generally well out on a wide track and sails increasingly flattened aloft but retaining a good curvature at the foot above the boom. This is to produce maximum drive through the water with low heeling and low leeway angles.

In high winds, sea conditions may force one to modify this procedure, but only slightly in regard to angular sailing, in all but extreme conditions. Sails must have a carefully graduated curvature from foot to head, that will accept the closest apparent wind angle at which a particular hull and keel can consistently sail in normal winds and seas at a correct angle of heel. Since *CONSTELLATION*, this apparent wind angle for a Twelve Metre must be expected to be some 20 degrees, and we find at the other end of the scale the X.O.D. angle is 24 degrees. Both types of boat for tactical reasons may be occasionally sailed 2 to 4 degrees higher. There is the possibility that *CONSTELLATION'S* successor may do even better!

Wool tufted sails show that to position the maximum "flow" too far forward or too full to accept the average angles demanded, completely defeats very close sailing at a low angle of heel (Photos 4 and 5).

The sails must be controlled by reducing curvatures as the wind increases so that as they are "flattened." The foot curvature of the mainsail is retained but the head curvatures become flat. On no account must the foot curvature of the mainsail under increasing wind pressure, be permitted to drift upwards to any bagginess aloft. If this is allowed—and it happened on the British Twelves when I was observing—a flat foot is created and the boom has to be trimmed in to nearly amidships in a breeze on a Twelve in order to get the fuller head to fill. This leads to excess side force low down and an excess drive high up with enforced over-heeling. Control of pitching becomes impossible and V/mg suffers.

It is now well known that *CONSTELLATION* borrowed small boat practice and controlled her single mainsail used throughout the Cup series by employing a masthead that bent backwards to flatten the mainsail head curvatures, whilst a laterally constructed oval bendy boom was bent in a curve to prevent the mainsail foot from losing its shape. Her control of heeling was exemplary. A special mainsail has been developed in this country and race proved over the past three seasons, that will automatically "flatten" controlled graduated curvatures with only slight spar bending, less than *CONSTELLATION* had to employ.

Close sailing at a low angle of heel cannot be accomplished at the high speed of a Twelve if the Genoa has its maximum curvature too full or too far forward just behind the luff, or if any bagginess is found near the head, for it will not accept the necessary low angle to the apparent wind. *CONSTELLATION'S* shallow curvature Genoa has confirmed this fact which was found on our models but not accepted at the time. Smoke and strings of chemical "soap bubbles" flowing around different curvature sails in natural turbulent winds out in the open air make this fact abundantly clear.

The helmsman must play his part in the proper control of angle of heel to prevent excess pitching and the evils of sailing free. For consistent optimum V/mg the boat must be sailed up to all useful gusts so that the sails are presented as far as possible at a constant angle of attack to the fine angle of apparent wind required.

Argument has raged over the so-called virtues of sailing to windward by water speedometer readings "to keep the boat driving at a best water speed for each wind strength." All our measured tests and performance curves have shown this to be a dangerous practice likely to reduce the consistent V/mg. To sail at a given speed through the water even when sailing up to the major gusts causes the helmsman to sail through too many of the more subtle advantageous gusts at a slightly coarse angle, which reduces the collection of many small V/mg bonuses gained at a temporary lower water speed but closer angle to the windward mark. It is true that there is a "best water speed for each wind strength," but as we have seen, it is not necessarily the fastest, nor can it be constant at all times, to obtain optimum "speed made good to windward." It often requires great self-control by the helmsman because the boat will frequently feel slow through the water at a low angle of heel. This is especially true when certain opponents are dashing off well heeled and appear to be going faster.

A significant test was made on my X.O.D. to try out "water speed sailing" and its effect on V/mg from the practical angle apart from V/mg measurements.

I sailed the boat to windward past a mark, as close to all useful gusts, etc., as is found to provide good racing V/mg. After 450 yards, measured by a rangfinder, a marker buoy was dropped. I then made a number of runs across the same course starting each time from the start mark, but now sailing with eyes on the waterspeed dial, trying to keep to a steady water speed based on the first "optimum" runs. An observer reported from his wind vane and speed instruments that I sailed up to the normal gusts as they arrived. It was, however, evident that I was ignoring the selection of the more subtle gusts or bonus getters, and I was also a trifle late for the bigger gusts because they had arrived and lost some of their sting before the indicated water speed altered. There is also a tendency to speed up the boat temporarily by sailing "slightly free" at a larger angle of heel when speed is seen to be dropping on the dial, which is a dead loss on close angle sailing for V/mg. The devastating fact was that in only 450 yards to windward the boat arrived on average 70 yards down to leeward each time from the original marker buoy reached "by the seat of my pants."

I was losing out on all those little close angular sailing bonuses that the human "computer" senses constantly gain by experienced selection, In a One Design keel boat racing class with a large number of boats, it is possible to say that any boat seen sailing at a large angle of heel particularly in difficult weather conditions, is not being sailed really close to every significant gust with complete optimum V/mg consistency, and it can therefore be written off as a potentially dangerous opponent. There are the "slicers" who part the waves, and there are "smashers" who smash their bows laid on their side against the waves—the "slicers" put up the best V/mg!

Pitch and its Control

Although over-heeling is I believe symptomatic of the main factors that create excessive pitching and poor V/mg, the following points must be given due consideration:

Pitch frequency resonance of the hull—if the natural period of the yacht is nearly the same as the period of encounter, the pitching will be accentuated, as it will also be with an over bluff bow entry. It is a simple matter to find the pitch frequency of any model or full-scale hull in a static position when afloat with a recorder and stopwatch. It is found that most asymmetrical hulls damp out an enforced pitch extremely rapidly. It is, therefore, unlikely to be a major cause of pitching, except when through other reasons the boat speed drops drastically and dynamic damping is reduced. Pitch frequency may then take charge, and it must be considered in this light.

A forward mast position as used by our Twelves has far greater "waving" leverage and adverse effect on sail angle of attack, than when the mast is positioned as centrally as possible consistent with sail area and proportion, as was achieved in *CONSTELLATION.*

The Americans concentrated crew and other weights centrally to retain one-finger helm balance to windward. This is usual keel boat practice, except when running when it is often better to bury slightly the bow with its lower resistance than to suck up water aft from a squatting stern.

Dynamic damping whilst sailing fast and holding a steady course is important. However, at a big angle of heel a steady course cannot be held because of yawing pitching in a sea, and dynamic hull damping is then largely lost.

Aerodynamic damping due to sails retaining a constant pressure is most important. But as we have seen, this constant sail pressure is lost when a yawing pitch develops through over-heeling.

It has been shown during our free sailing model tests that a highly unconventional shallow Twleve Metre model hull which I designed, can be produced within the rating rules. During the sailing tests of this 1/9th scale model, angles of heel were shown to be considerably lower in a good-scale breeze to hard-scale conditions, and a superior V/mg was measured as against our yardstick conventional model American Twelve. An unconventional hull should therefore not be ruled out as a possibility of the future, although it may be unlikely for some time to come.

Summary

The following conclusions regarding pitching and its attendant factors may be summarised—

1. A symmetrical hull is less likely to effectively damp out pitching than a asymmetrical shape, at a controlled angle of heel.

2. A well-designed and "stiff" asymmetrical hull, with damping stern to suit, will effectively damp out any reasonable bow excitation, if the yacht is sailed at a moderate angle of heel which can be specified.

3. Angle of heel becomes an indication of good health, or ill health, in a yacht's development and the way it is sailed to windward when seeking an exceptionally good V/mg. An over-heeled boat should create suspicion at once.

4. The mast should be located as centrally as possible, and should be arranged to bend for sail control, and also flex at the head in excessive wind gusts to provide a measure of automatic heel control.

5. The boom should be constructed laterally oval and bent as desired to retain the mainsail's good "flow" at the foot, and prevent the foot curvature from drifting aloft into bagginess where it will create excess heeling accentuated by greater side force from a "flat" footed sail.

6. Both sails must have curvatures that will accept the finest practical apparent wind at which the hull and keel can sail at a low angle of heel.

7. Any bagginess, developing from increasing pressure in high winds, in the upper areas of Genoa or mainsail will ruin V/mg. The maximum curvature of the Genoa, although further forward than in the mainsail, must not be located too far forward or the boat will not point high for optimum V/mg.

THE NOON POSITION

Three Sights Around Noon Give Both Latitude and Longitude within Moments.

BY

ARTHUR PIVER

Our method is so simple there is room in it for neither theory nor diagrams. After sights are taken, only two major steps are required for either Latitude or Longitude.

This presupposes knowledge of use of the Sextant—which is described in usual navigation books—but better yet by some individual who possess an instrument and is willing to demonstrate its use. Use of the Sextant naturally includes the ability to read the angle shown therein.

Latitude

Let us start with determination of Latitude—which requires a Sextant reading (at Noon) when the Sun is highest in the sky. At time of High Noon the Sun will be directly *true* North or South of you. If you are in the United States it is *always* South. Thus when the Sun is approaching True South of your location, you can begin taking sights (you need a clear horizon to the South). Beginners' sights should be taken from land—for then you do not have the complication of a moving boat and you can check your results, for you should know exactly where you are.

The two major steps for determining Latitude are:

1. Sextant reading is *subtracted* from 90 degrees—which for simplicity may instead be written 89 degrees ( ) 60 minutes ('). You will note that the above figure adds up to 90 degrees.

2. After subtracting the sextant reading from 90, the answer is added or subtracted (according to a simple formula) from the figure given in the Declination Table. The answer is your Latitude!

There are some minor steps:

a. The Sextant reading must be corrected for a possible error in your particular instrument (Index Error); and

b. The Sextant reading must be corrected for the altitude shown and the height of eye above sea level. We do this with one entry from a table, which is always *added* and is always shown in *minutes.*

These particular *minutes* refer to portions of a *degree* and not to the customary minutes of Time. A Degree is composed of 60 Minutes and a Minute is composed to 60 Seconds. This is the most complicated part of the arithmetic we use—for when adding or subtracting we are limited by the figure 60. If we have to subtract a larger number from a smaller, for instance, we have to borrow 60 seconds (or minutes) from the preceding digit.

Although Degrees are composed of minutes and seconds, in navigation seconds are usually shown as tenths of minutes. As one-tenth of a minute is six seconds—then, for example, 18° (seconds) will equal 0·3' (minutes).

c. We have to label our Sight either North or South. In the United States we are always North of the Sun so we label it *North.*

The Declination Table shows the Declination for our particular day as either North or South—and following is the Rule which tells us whether to add or subtract in order to find our Latitude: if the two names are the same (North and North or South and South) we *add;* if the two names are different—we *subtract.*

Read the above over again—we won't work examples until after discussing the next step—the determination of Longitude.

Longitude

With our method, Longitude is found by first determining the exact time of High Noon—which is then quickly and easily converted to actual Longitude by means of the Nautical (or Air) Almanac.

This is based on an old-time technique entitled "Equal Altitudes at Noon."

We find the exact time of High Noon by taking a sight *before* Noon and marking down the time; and then taking another sight *after* Noon (again marking down the time)—using the *same* Sextant Angle. Adding the two times together and then dividing by two gives us exact time of High Noon.

You will note in the Nautical Almanac that the first column (under Sun) is marked G.H.A. This actually *means* Longitude—it is the same thing—and if we apply the exact time of High Noon as found above—there is our Longitude!

Dear Sir,

When you receive this, you'll know I've arrived in Bridgetown, Barbados. At present, *KLIS* is running under twin staysails before a boisterous force 6 Trade-wind, about 700 miles from Barbados.

To bring the story up to date, the early part of the cruise, from Barrow to the Scilly Islands, was a long tale of adversities; gales, calms, headwinds and other delights of the British climate. The result was that, having to beat off a lee shore into a full gale, then on the same passage, run before another one, by the time she reached the Scilly Islands, both boat and skipper were tired. A glued joint in the cabin wing structure had failed and the main hull was "panting" too much so ten days were spent strengthening her up. The lesson learnt was that the cabin structure must be as strong as the hull, to withstand the pounding of the seas.

All being fixed, we boldly set off for Spain. As was to be expected in late October, we took a pasting in Biscay. The wind had risen to force 8—too much for the "twins"—so I'd been at the helm a good while, running under storm-jib. I was very nearly asleep when a huge wave caught me off guard and *KLIS* broached-to violently at high speed. She must have heeled over to about 80°. The lee float was buried. The cockpit filled up and things went flying generally—pretty frightening. After that, she lay ahull for 24 hours, making about 2 knots of leeway with the dagger boards up, while it blew force 8-9. She lay very quietly, except for the odd wave that would break right over her, throwing her bodily sideways. I spent most of the time drying in my bunk.

Fortunately, we were drifting in the right direction and made the 400 mile passage to La Corunna in 4 days 6 hours. I had some very pleasant cruising in Northern Spain and then went on to Lisbon and from thence direct to Las Palmas in the Canary Islands.

The main lesson learnt was the need for a wind-vane self-steering gear. At Las Palmas, I met up with 4 other yachts, all making self-steering gears so material resources and technical know-how were pooled and a good time was had by all. *KLIS* gear is a simplified Hasler-type trim-tab gear, mounted on the cheek of the rudder so that the rudder can still be raised. "Fred" as he is called, has been an absolute Godsend. Apart from one breakage, he has brought us thus far with very little trouble. His only drawback is that he works better on port tack than on starboard, when he usually needs an elastic on the tiller. I think the reason for this is that the tab, being mounted off-centre (to starboard) has a drag producing a turning moment on the rudder.

I left Las Palmas, single-handed still, on 15th January. The fine breeze soon fell away, and with light variables and calms, we only made 90 miles in the first 24 hours. Since then, when the Trade wind filled in, my worst run has been 120 miles and the three best days runs are 170, 171 and 172. I've decided to try to do the passage (2,800 miles) in 20 days, the present single-handed record being 24 days held by Bill Howell with *STARDRIFT*.

The best wind, where the big runs are made, are force 4-5, when I can just hang onto the "big twins" (consisting of spare mainsail and Genoa) and the seas aren't too big. As the wind and waves increase, she starts to broach sometimes as a wave throws the stern sideways and, as the wave-crest overtakes her, she dives her nose into it at about 12 knots and brings up with a terrific jerk as the bow waves smash against the cross beam and cabin.

I have trimmed her down by the stern which helps a lot and I wish I'd fitted spray deflectors, but even so, I think the only answer for high speeds in big waves is a big tri.

In force 6-7 winds, of which I've had plenty, I reduce sail till the average speed is around 6 knots, i.e., she surfs at 8-9 knots for a few seconds, then drops back to 4 knots as the wave crest overtakes. Any faster pace, though exhilarating for a while, becomes hard on the nerves afer a few days, and the noise and motion make sleep difficult.

SATURDAY 4th February. Arrived 0750 hours, 19 days, 22½ hours out. Best day's run was 180 miles. *KLIS* looks battered, the varnish-work being completely "shot-at"—but she made it.

Many thanks once again to the A.Y.R.S. who make these things possible.

Yours sincerely,

BERNARD RHODES.

Yacht *KLIS* in Mid-Atlantic.

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30th January, 1967.

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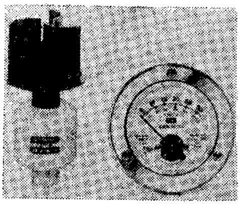

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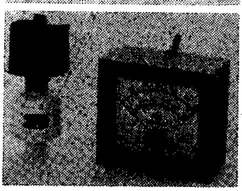

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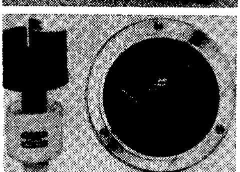

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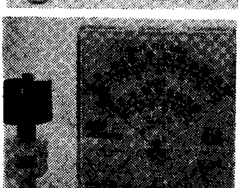

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