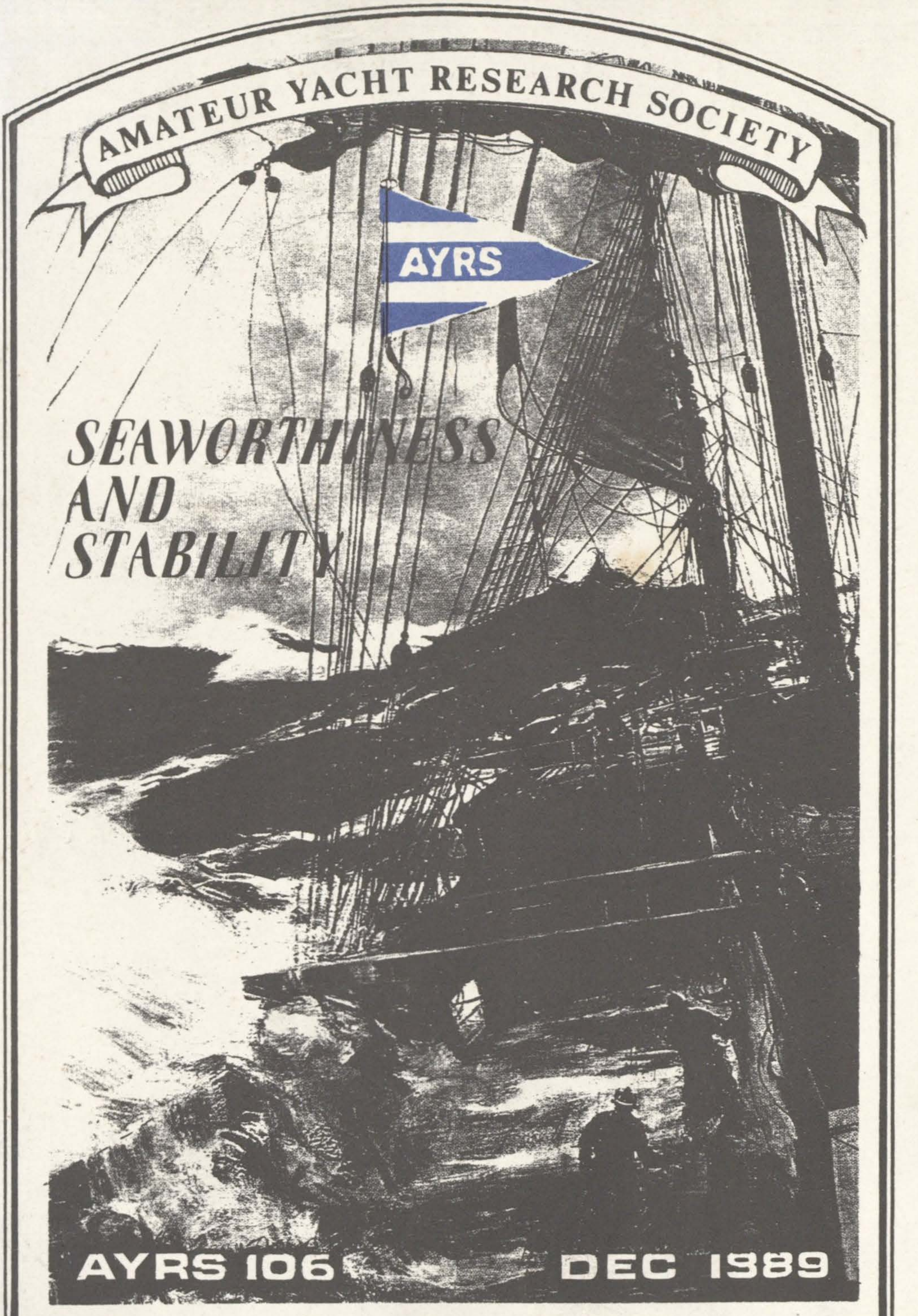
AMATEUR YACHT RESEARCH SOCIETY
AYRS
SEAWORTHINESS AND STABILITY
AYRS 106
DEC 1989

AMATEUR YACHT RESEARCH SOCIETY

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Publication 106 December 1989

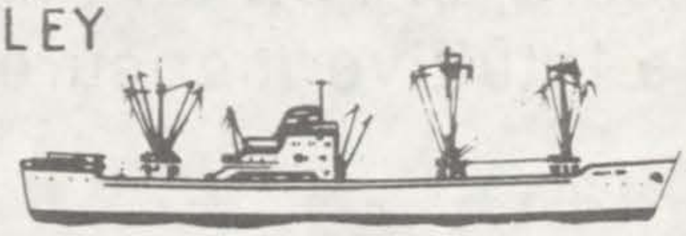
Editorial

The time is ripe for another survey of work on seaworthiness and stability. Recent articles in the yachting press have focussed on the effects of racing yacht design on the tractability and seaworthiness of cruising yachts, there have been several dramatic multihull accidents in shorthanded ocean races, and the Society's Public Lecture at the Earl's Court Boat Show in January 1989 featured professor Tony Marchaj on the subject of seaworthiness. Tony Marchaj is well known for his views on the seaworthiness of the modern racing yacht, and he developed the theme in a most entertaining way at the Boat Show. In order to provide balance, or spark controversy, we are also putting forward another point of view on the seaworthiness of the IOR yacht.
In addition to the account of professor Marchaj's lecture, this volume include other articles on the subject of seaworthiness and stability. These range from the innovative practical design work of Paul Ashford to the highly technical leading edge work of Fiona Sinclair.
The topic is one of interest to us all; the editor of this publication became more than theoretically interested during the summer of 1988 when his quarter-tonner lost her rudder in a Channel gale. The form stability of the small IOR yacht, together with the use of improvised sea anchors and the services of the RNLI are to thank for the appearance of this publication. Although not yet weaned off monohulls, the editor has at least had a test sail in a multihull and is seriously contemplating purchasing one when funds permit the return to yachting as opposed to dinghy sailing. Anyone looking for a crew for RBR 1993 ?

C. Norris

THE TRUSTEES OF THE ERIC TWINAME MEMORIAL TRUST ARE DELIGHTED TO HAVE ASSISTED AYRS BY MAKING A CONTRIBUTION TOWARDS THE COST OF THIS PUBLICATION

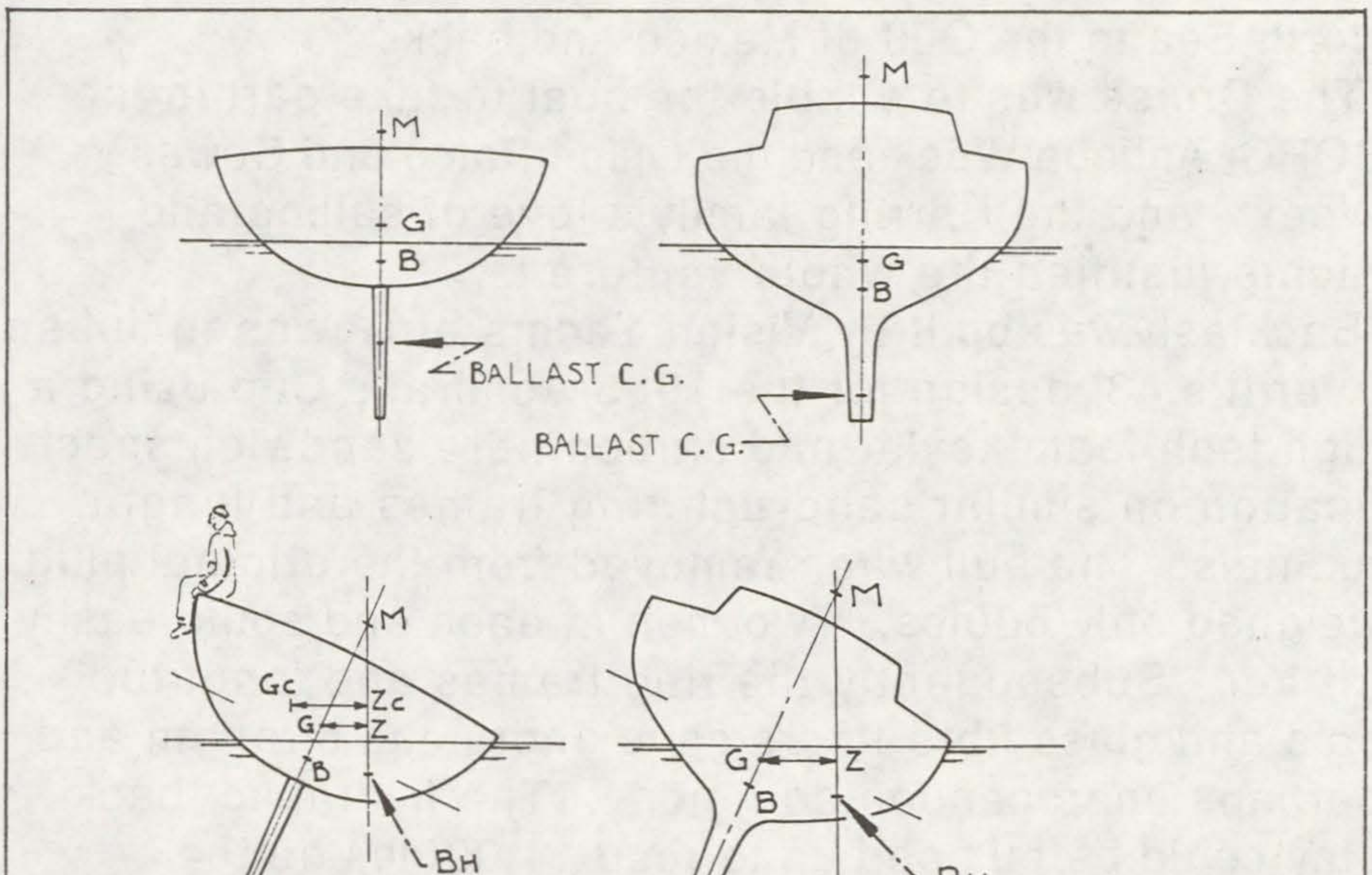
DESIGN AND LAYOUT BY JOHN CADLEY



Introduction-Seaworthiness and Stability

To a certain extent, we must compromise in the definition of seaworthiness; although the concept is an ancient one and is utilised in shipping law to attach liability, it unfortunately lacks clarity. 'To the seeker after precision in law, seaworthiness is a disconcerting doctrine because by its very nature, it is not reducible to exactitude. It is relative and a nebulous term; it does not lend itself to easy application or absolute definition' this quotation, taken from the SURVEY OF MARINE DOCTRINE OF SEAWORTHINESS, adequately reflects the confusion associated with seaworthiness. there is however, a disernible agreement among people who have ventured upon the task of defining this elusive term. For example: a seaworthy vessel is one 'prepared to resist and if possible to overcome the perils of the sea'; or a vessel'in a fit state as to equipment, crew and in all other respects, to encounter the ordinary perils of the sea'; or a vessel 'that is fit to withstand wind and waves in heavy weather, and to ride out of storm and claw off the lee-shore'; or a vessel which has 'that degree of fitness which an ordinary careful and prudent owner would require his vessel to have'. the common thread which goes through all these definations is; to be seaworthy, the vesel must be able to defend herself against the incursion and perils of the sea.In many yachtsmens minds, the two factors uppermsost may well be stability and ability to make to windward. Stability depends on the inter-relationship between the centres of gravity and the centre of buoyancy of the craft, a common sense measure being, perhaps the amount the gunwhale dips when one steps aboard, or how far the vessel heels when sailing. These are intuitive measures of "static stability", the formal

and mathematical descriptions of this kind of stability being much used since the 1979 Fastnet Storm and the publication of the official report.
It is now common knowledge that the shape of the yacht and its weight distribution confer "form stability" and "ballast stability" respectively. The figure below illustrates the point. These are static measures, however, and the yacht in fact operates in a dynamic environment, perpetually moving in three dimensions subject to the forces of the sea. This was the fundamental topic of the Earls Court Lecture by Professor Tony Marchaj.



Ocean Cruising in an IOR Racer

Tim and Cathy Herring were the original owners of "Backlash", one of the most successful IOR racers ever. Backlash is still a regular Solent racer, a sleek silver craft which now bears the name "Toy for the Boys".
In 1986/7 the Herrings took Backlash across the Atlantic, recording their adventures in the RORC magazine "Seahorse". Their account of this voyage certainly contrasts with Tony Marchaj's verdict on the IOR yacht !
"It is not generally considered likely that a flatout high-tech IOR racer makes a suitable vessel in which to undertake a family cruise of the Atlantic from the North Sea to the Gulf of Mexico and back."
"The Cruise was to enable the boat to take part in the SORC, Antiqua Week and the Onion Patch and Cowes Week - and the Herring family's love of sailing and racing justified the whole venture."
"Backlash was built by Vision Yachts of Cowes to Julian Everitt's 43' design for the 1985 Admiral's Cup using a high tech foam kevlar and carbon fibre sandwich specification on similar sandwich ring frames and longtitudinals. The hull when removed from the original plug weighed only 600lbs. Two men at each end could easily lift her. Subsequently the ring frames and longtitudinals and glass fibre floors gave enormous strength and perhaps unprecendented rigidity. The hydraulic backstay could be pumped up to read 11,000lbs on the forestay load cell with less than 1/2" hull deflection."

"The mast head rig by Sparcraft provided a tapered four spreader very flexible spar with permanent backstay, runners, checkstays and babystay. This spar with its discontinuous rod rigging has now completed a trouble free 25,000 miles sailing - perhaps equivalent to a normal 6 years use without replacing anything other that runner tangs."

"A variety of keel and canard (forward dagger board) configurations have been developed on Backlash but an unusually fat section semi-elliptical keel was used for the voyage."

"By the 2nd January we were 2,700 miles out - the speed at times excessive - our heavily laden racing boat reacting perfectly to every wave and controllably - but at such speed and with such seas every movement was an effort, every task required thought. Crawling on all fours from crouched handhold to handhold became necessary."

"The speed record was won by Jamie when during one glorious long sleigh ride in which the boat seemed to be running on a set of rails and yet could be steered with complete precision and ease - the speedo clocked up a steady 21.5 knots and held for perhaps 10 seconds then dropped back to a mundane 11 or 12 knots only to rise again on the next wave. It was exhilarating for day after day and explains why the log recorded an average 200 miles a day over the whole voyage to Florida."

"The same wind that blows continually westwards counter to the earth's rotation blows not only such as we to the Gulf of Mexico but also the sea and surface current of over 1/2 knot, perhaps as much as 1 knot flows in the same direction. In 24 hours the surface drift can add as many miles to the distance travelled and so thought must be given to the frequently experienced danger of an unexpected early arrival in the coral reefs of the West Indies."

"The I.O.R. has at last produced strong fast boats which are safe and rewarding to sail. The fact that they are often raced to the edge of endurance is because people want to race that way! They don't have to. There always has been an advantage to be gained from sitting out on the rail - when I was a boy we used to lie along the rail Star fashion with one leg over the side just as they do on the twelves. The IOR's racer won't fall over if you don't sit out but it might go a fraction slower for the last 1/10th of a second advantage. It's fun."

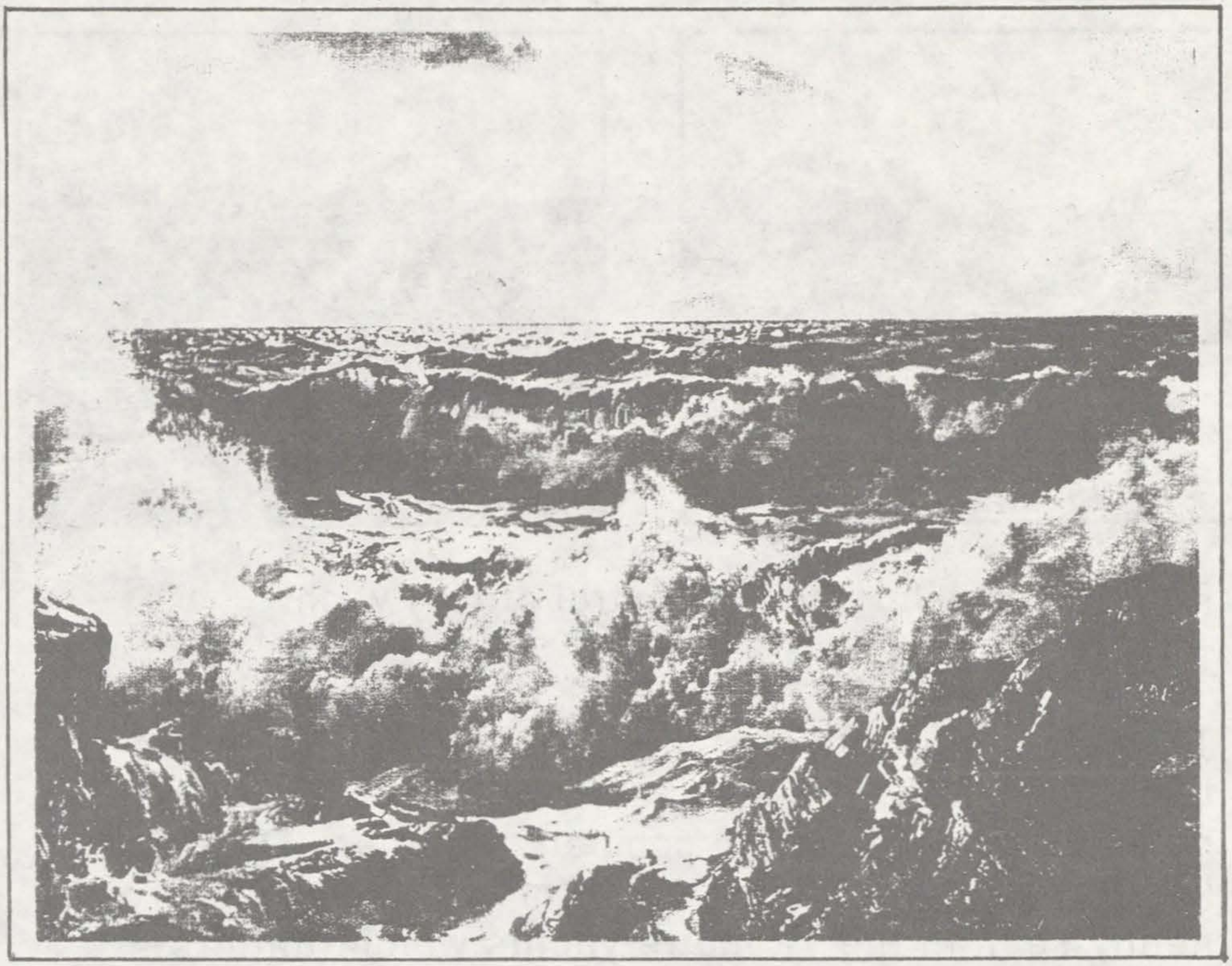
"We found that in all our miles between racing in the SORC, Antiqua Week, Onion Patch and Cowes/Burnham we never had the slightest anxiety about the boat's stability or stiffness and seaworthiness with all but the helmsman down below."

"The present generation of IOR boats are really superbly seaworthy vessels. They go to windward a great deal better than any sailing boat has ever done before - even in the most appalling conditions. They make fast passages and providing their skippers don't insist on leaving full sail up in all weathers they are very tractable and don't career about uncontrollably all over the ocean. This was not always so - in the 60's and 70's IOR boats suffered all manner of difficulties - steering stability, structural weaknesses but as in all spheres of human endeavour the evolution of engineering development was refined up the point where things broke - then were beefed up again."

"The modern high tech construction for an IOR yacht is lighter and stiffer than anything built previously. The search for these qualities has led to the development of Epoxy resin techniques used with carbon kevlar foam and wood. Gone are the days of cracked glass fibre and flexing panels and since the first attmepts at multiple spreader rigs in the 70's we now have more reliable rigs which are lighter, stronger and more flexible than before. The same sort of evolution through IOR pressure has resultes in winches, blocks, sails and running rigging all becoming lighter and stronger."

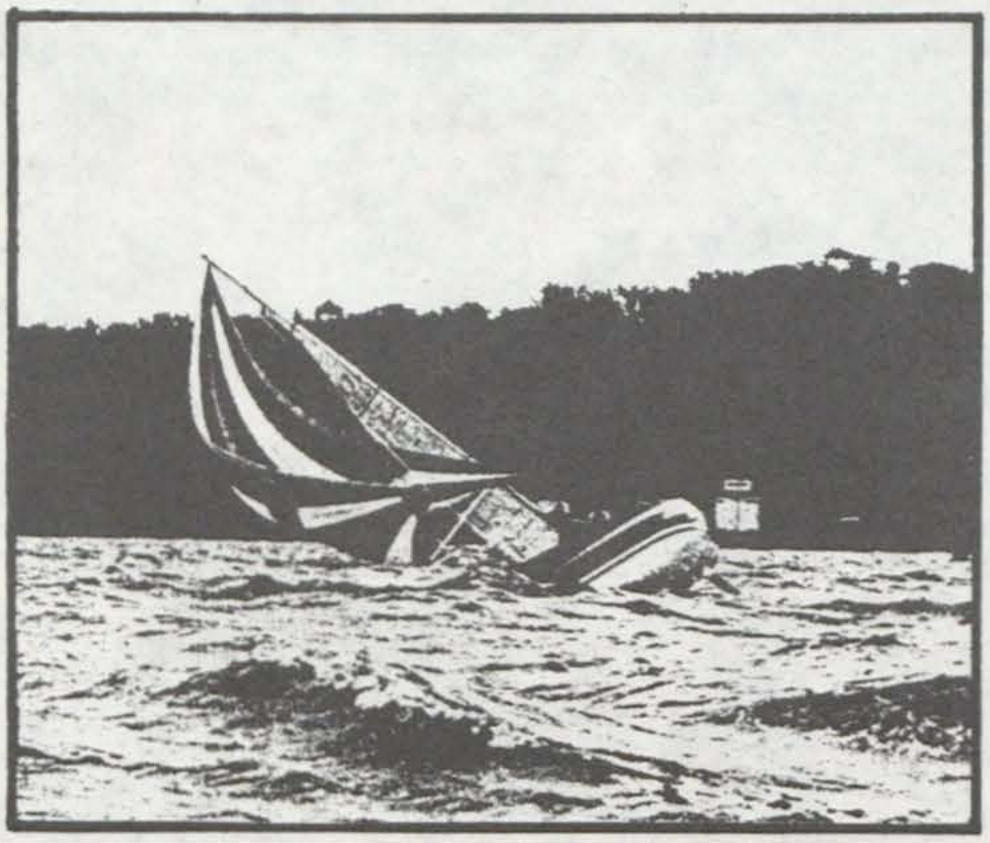
"The rule has at last resulted in the boats beginning to look sensible and beautiful with less extreme stern shapes, smaller fortriangles and lower freeboards with the disappearance of unseaworthy top hamper."

"One day perhaps we will even be able to overcome the difficulties of measurement by tape measure which still causes the unfortunate and somewhat laughable measurement point 'bumps' still in evidence on other people's boats."



EARL'S COURT LECTURE, JANUARY 1989

The topic of the 1989 Earl's Court Lecture was SEA-WORTHINESS and our speaker was Professor Tony Marchaj, of Southampton University. Professor Marchaj opened his talk with a slide show , demonstrating the difficulty of controlling racing yachts designed to the International Offshore Rule (IOR) in strong winds. Fig.1 is typical of the problem of control, especially downwind in winds of Force 6 and above.



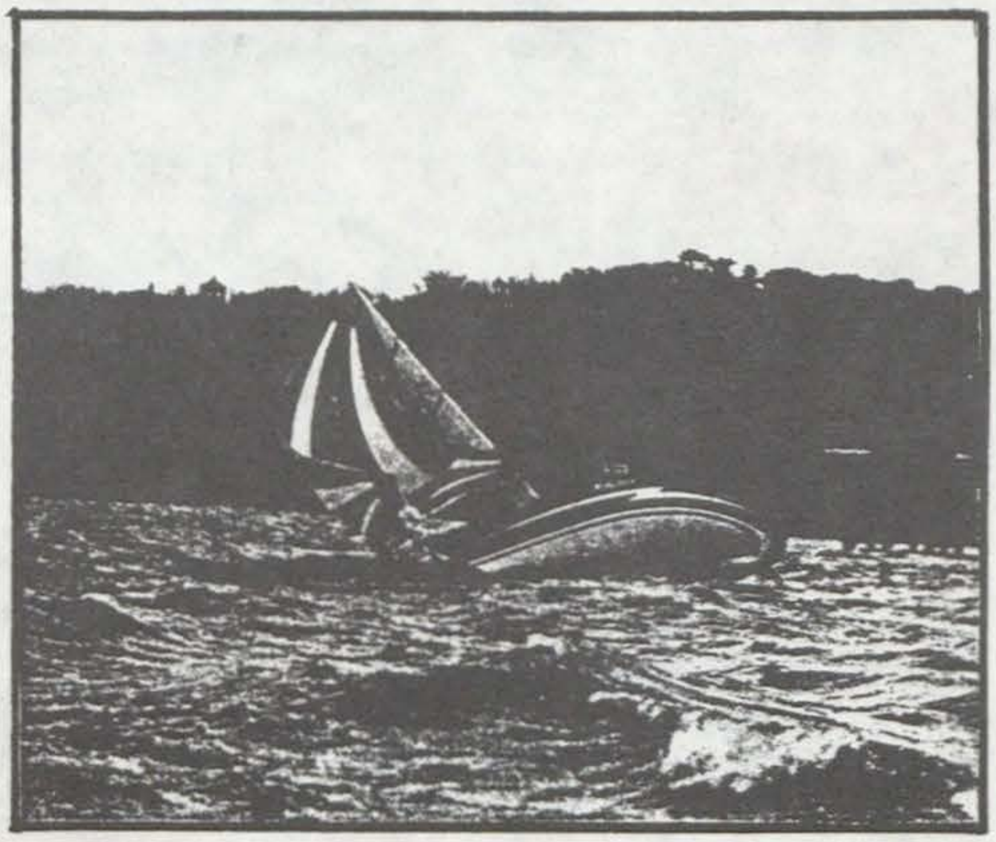


Fig. 1 Downwind lack of control of IOR yacht

The IOR is only one of many racing handicapping systems, designed to allow yachts of differing sizes and potential performance to compete together. One of the longest lasting of these is the metre rule, most prominently seen in the 12 metre yachts which, until recently, competed for the America's Cup. The metre rule or International Rule takes the basic form:

$$\frac{L + 2d + \sqrt{Sa} - F}{2.37}$$

where l = length of hull
d = girth difference
Sa = Sail area
F = freeboard

The term d, given girth difference is the difference between the skin girth and chain girth (see fig, 2 below) and is intended to encourage seakindly hull forms, and conversely penalize extreme forms.

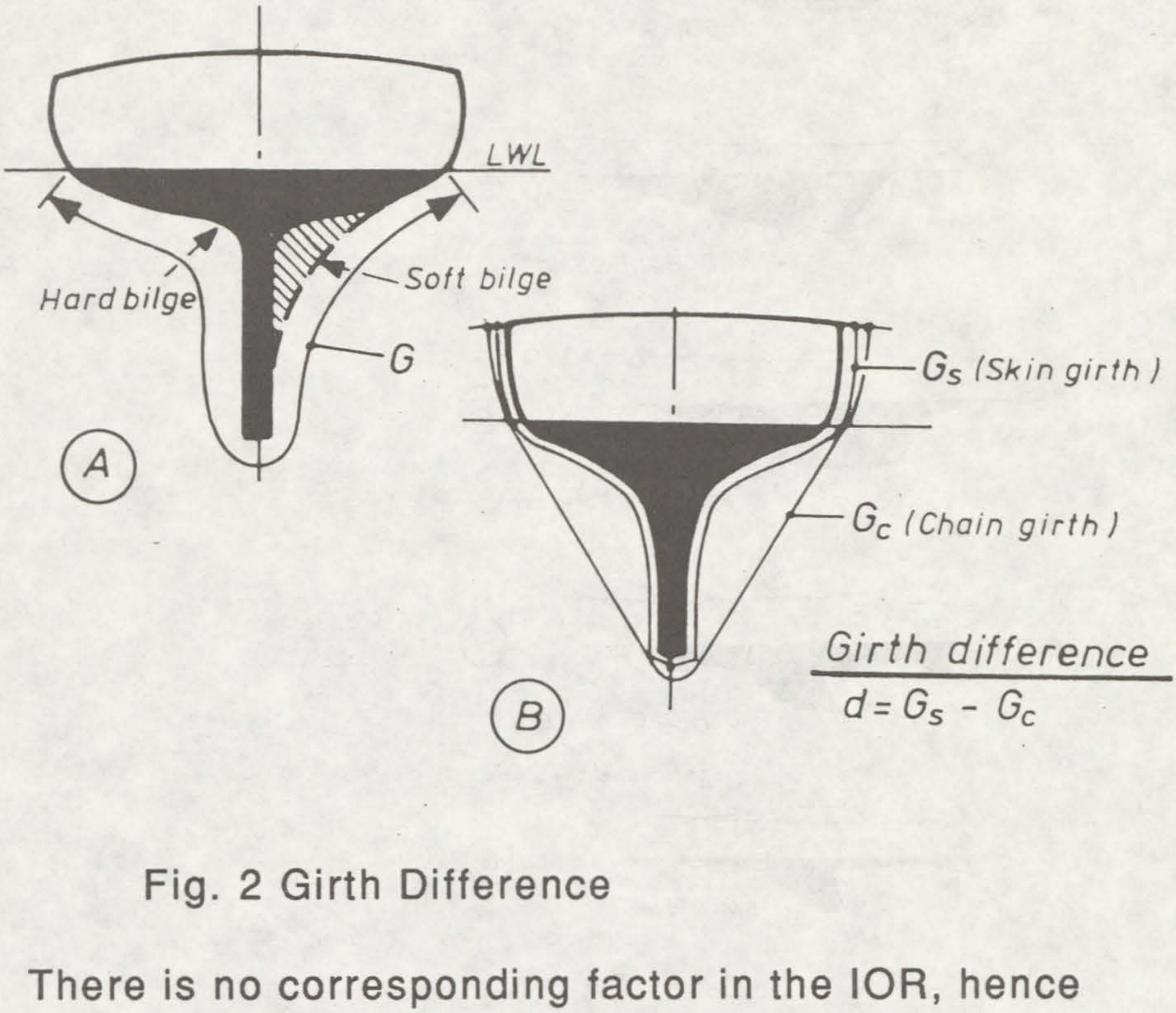


Fig. 2 Girth Difference

There is no corresponding factor in the IOR, hence "Seaworthiness - The Forgotten Factor" is the title of one of Marchaj's better known books on the subject.

The influence of, on the one hand seafaring tradition, on the other hand racing rating rules on hull form was discussed , the trends being summarised in fig. 3.

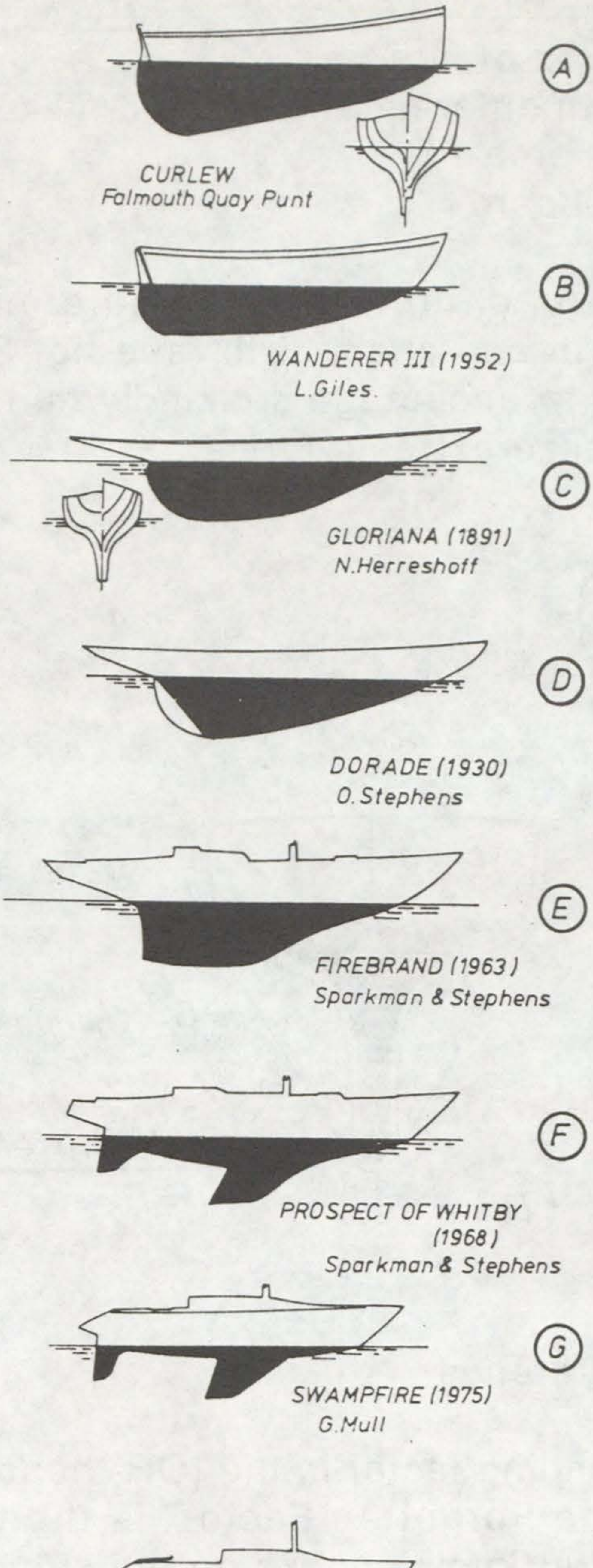


Fig. 3 Evolution of the sailing boat hull

We were then talked through the various motions of a yacht in a seaway:

1) Rolling - The boat heels rythmically from side to side about it longtitudinal axis.

2) Pitching - The periodic motion which buries the bow and then begins to lift again.

3) Yawing - Lurching or swinging to either side of the course.

4) Surging or Surfing - The tendency of a boat sailing downwind to accelerate on the face of a wave, and decelerate on the back and in the trough.

5) Swaying and Drifting - An oscillatory forming of sidling in which the boat moves bodily alternately to port and starboard of a mean course.

6) Heaving - The vertical bodily movement of the whole boat upwards and downwards about the average still water level.

Of these various motions, Professor Marchaj then concentrated on the accelerations due to two of them, rolling and heaving. Two graphical illustrations of the lack of stability induced by the combination of these motions were given. The first, the girl on the swing (fig. 4), shows how the rolling motion induced by waves (push from man) is augmented by the heaving motion of the boat in the waves (the girl swinging her legs).

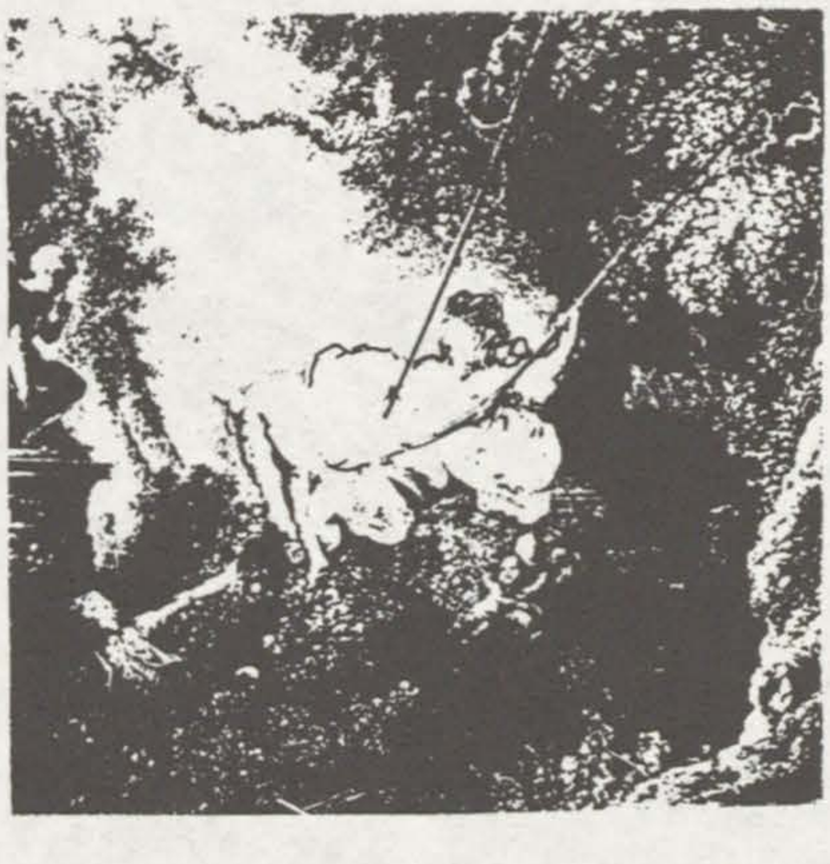


Fig. 4 The girl on the swing

The second example was even more convincing. Tony started to swing his pocket watch on the end of a chain (rolling) and then jigged the swinging watch up and down (heaving). It did not take long before the watch went "over the top" as the two motions added together. This corresponds with the real life situation of the yacht in waves. There is a well known phenomenon of sailing boats capsizing on the crest of even smooth topped waves formed by, for example, the bars at the entrances to harbours. This is caused by the effect of heaving in waves affecting the vessels stability by varying the apparent weight (the same effect we experience when ascending or descending in a lift, caused by acceleration and deceleration). Captain Mottez of the French Navy discovered that, in waves about 26 feet high, the weight of objects on board his frigate appeared to be about 20% higher in the trough of the waves, and about 20% less on the crest. The higher and steeper the waves, and the shorter the period, the greater are the accelerations of the vessel and consequently the bigger the reduction in stability on the wave crest as compared with the static stability in calm water. if, on the crest of the wave the vessel is subject to a heeling force from the wind, the reduced stability may not be enough to resist a capsize. This is illustrated below in Fig. 5.

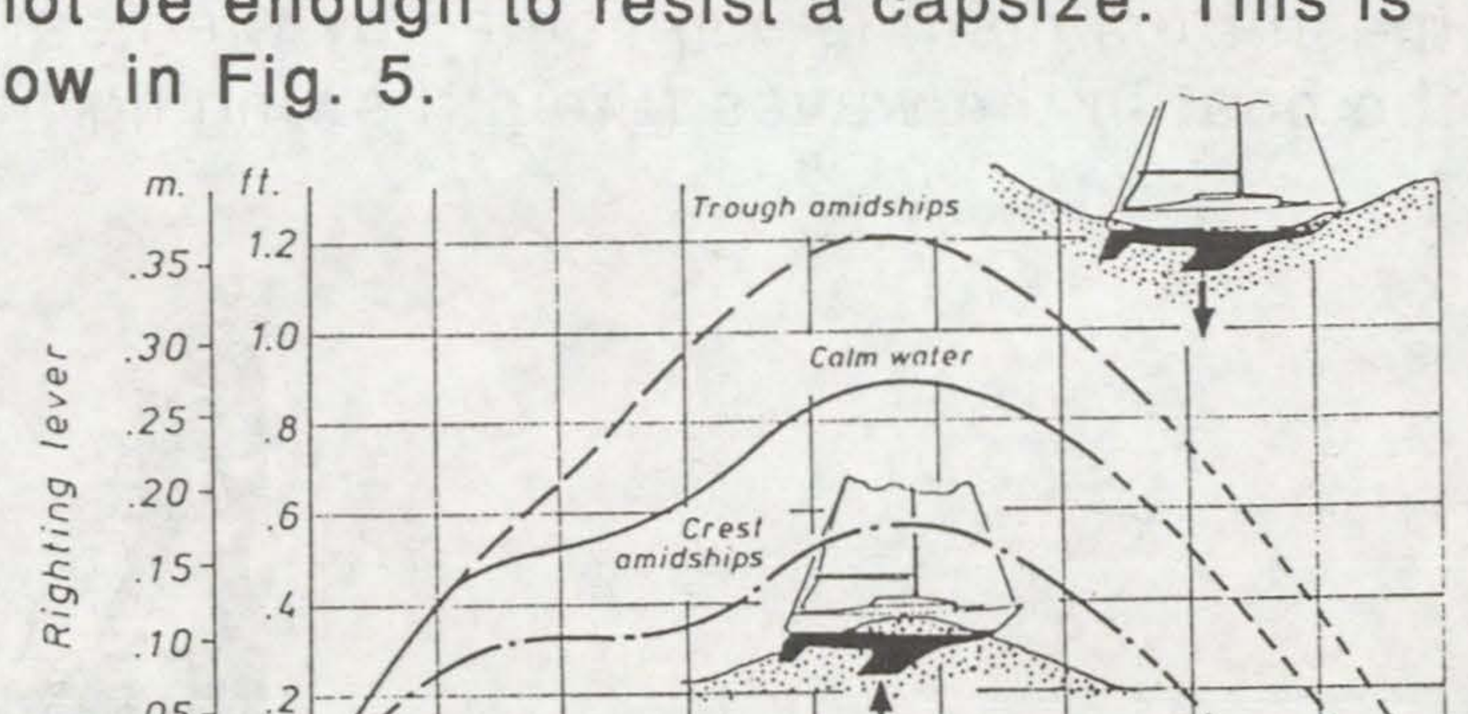


Fig. 5 Reduced Stability in Waves

A further effect of accelerations is that on crew performance.Experience has shown that when a boat is pitching, heeling or rolling, the ability of the crew to perform its function may be seriously impaired. Sea-sickness is the obvious manifestation, but the charts below show that with rolling, after an initial slight improvement in performance their is a steady decline towards incapacitation, while accelerationsalso have a debilitating effect.

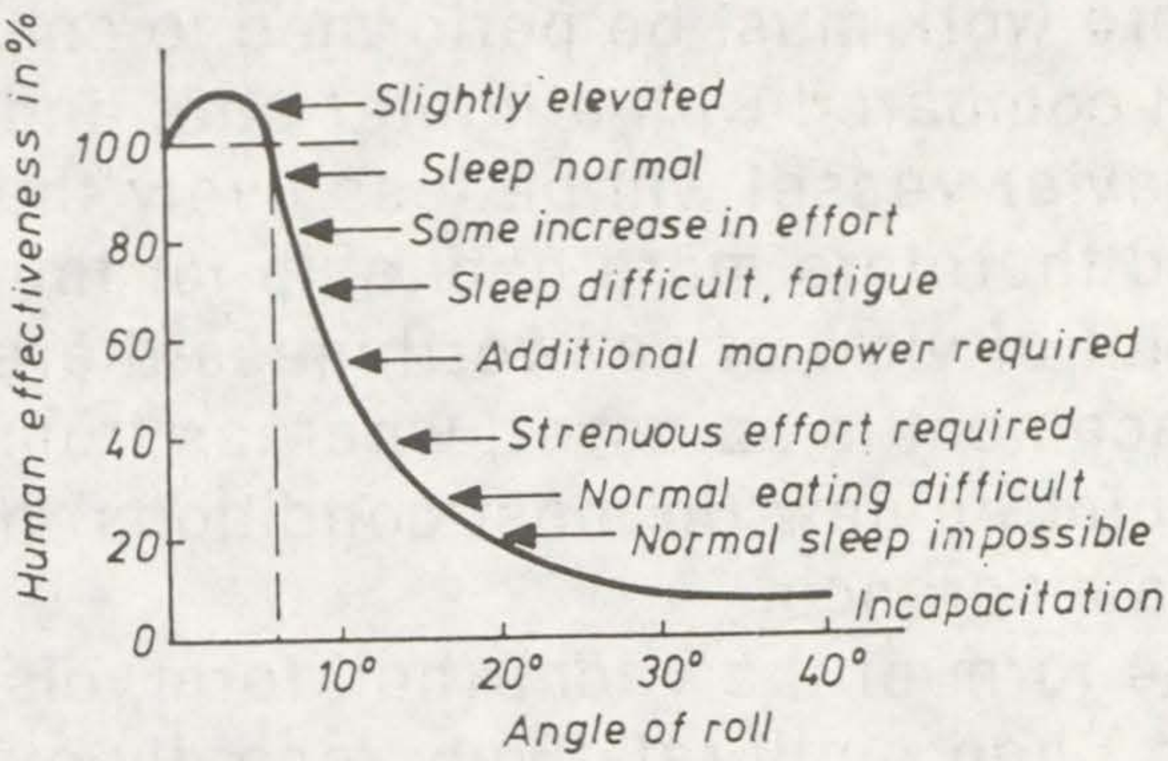


Fig. 6 Effects of Rolling on Crew Performance

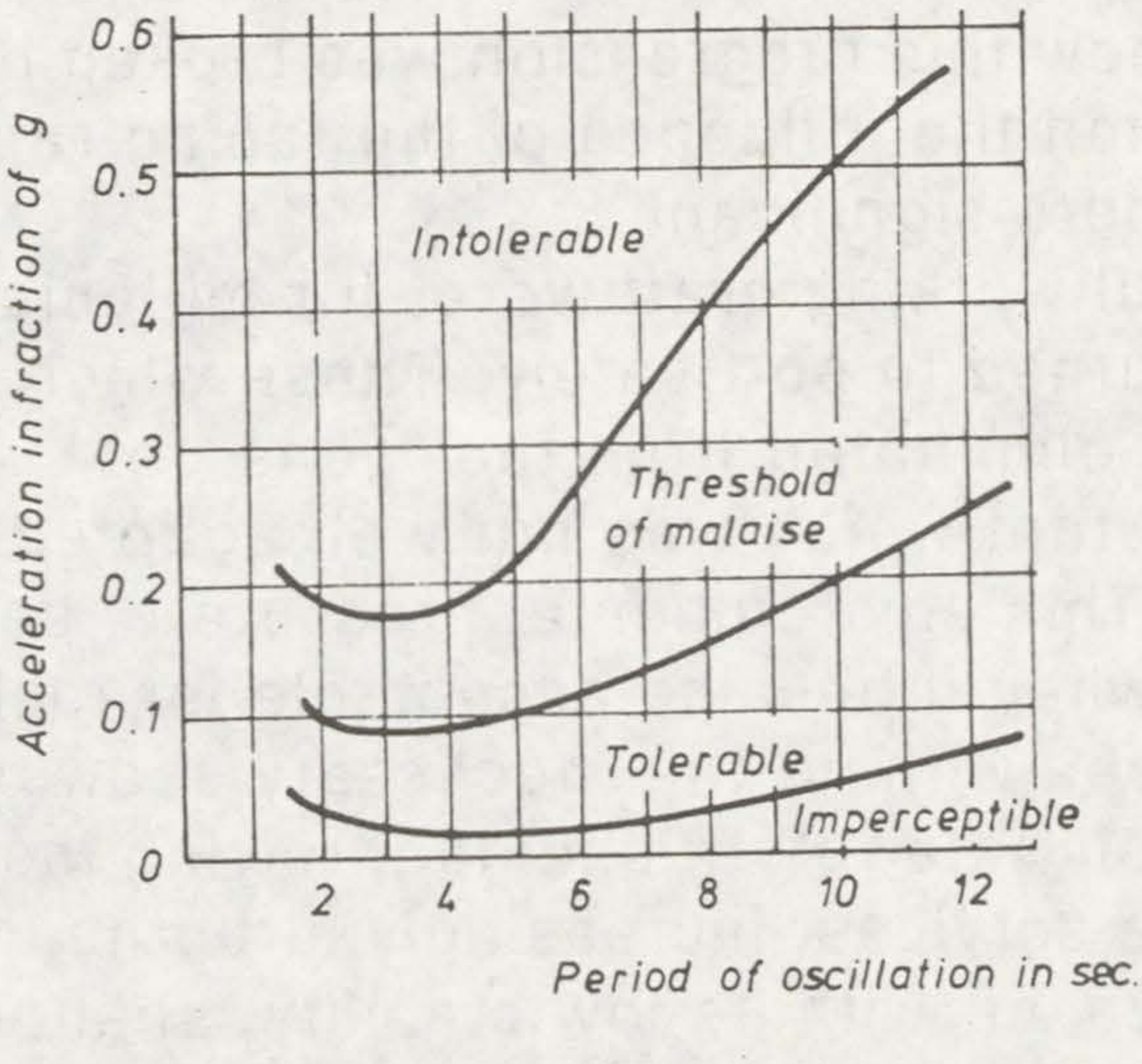


Fig. 7 Effect of Acceleration on Motion Sickness

The well known equation F = MA (Force equals mass times acceleration)
demonstrates an inverse relation between mass and acceleration, and therefore a relation between the displacement of a vessel and the accelerations it will experience under the influence of wind and waves.
We have seen that high accelerations are deleterious both to stability and to crew performance.
More work must be performed to capsize a heavier vessel compared with a lighter one, and the motion of the heavier vessel will be less lively than the lighter one and therefore more habitable for the crew. From the point of view of seaworthiness therefore, heavy displacement is an asset, whereas from a performance ppoint of view (in most conditions) heavy displacement is a hindrance.
The form of the yacht (hull form, displacement, rig etc.) had, until relatively recently evolved over a considerable period of time from earlier working craft, a process of natural selection taking place somewhat akin to Darwinian selection in the biological world. Fig. 3 shows how this progression was broken in the late 1960's when the influence of the racing rating rules became more significant.
Successful working craft were, for millenia, those which returned to port safely. Those which did not return were eliminated from the "gene pool" like a biological mutant which was not well adapted to its environment. This environmental pressure of selection was removed when it became acceptable for racing yachts to put to sea without the necessary seaworthiness to ensure their safe return unaided, relying instead upon the rescue services, increasingly airborne.
The IOR yacht, with its low stability, shallow body and poor directional stability is a mutant which could not survive without this intervention.

Aerodynamic Stability in practice !

AYRS Committee members Norman Champ and James Byam Shaw accompanied Fiona Sinclair to Whitby in March 1989, in order to put her theories to the test.

A fishing vessel equipped with one of James' special rigs (to be described in publication 107) was used as the platform for sensors and data gathering equipment from London University. Working in a smelly fish-hold in a rolling and heaving fishing boat was a far cry from the laboratory, but Fiona is now able to refine her theories in the light of experience.

AERODYNAMIC STABILITY

by
F.M. Sinclair
Mech. Eng. Dept, University College London.

Static stability is a yacht's ability to return to upright when tilted over (in harbour).
Dynamic stability is its ability to damp out wave-induced motions such as rolling (while sailing).
These two effects are not always compatible, and may occasionally have conflicting requirements.
Dynamic stability is partly hydrodynamic (from the hull and stabilisers) and partly aerodynamic (from the sails).

Researchers often find that altering a wingsail shape to give higher thrust does not necessarily give the speed increase which they predicted. This is because the adjustment also alters other forces, in particular the roll damping moment, and this may sometimes have more effect on the speed than the thrust increase does. As rolling motions slow a yacht down (because of friction between the hull and the water), it is obvious that damping the rolling should speed it up.
However, optimum sail configurations for thrust and for damping may conflict - i.e. if you are greedy and try for too much thrust, you may decrease the damping so much that you end up decreasing the speed, or even capsizing the yacht. Care must be taken to optimise both thrust and damping together, to get the highest resultant speed.

This article is a summary of 'Motion damping of ships fitted with marine aerofoils', by B.R. Clayton & F.M. Sinclair, published in Transactions of R.I.N.A. (1988).

When a yacht rolls from side to side, the effective (apparent) wind speed fluctuates in magnitude and direction, with small harmonic increments, dV and $d\alpha$, giving corresponding fluctuations in the aerodynamic forces. See Fig. 1 for illustrations of the lengths, angles and windspeeds.

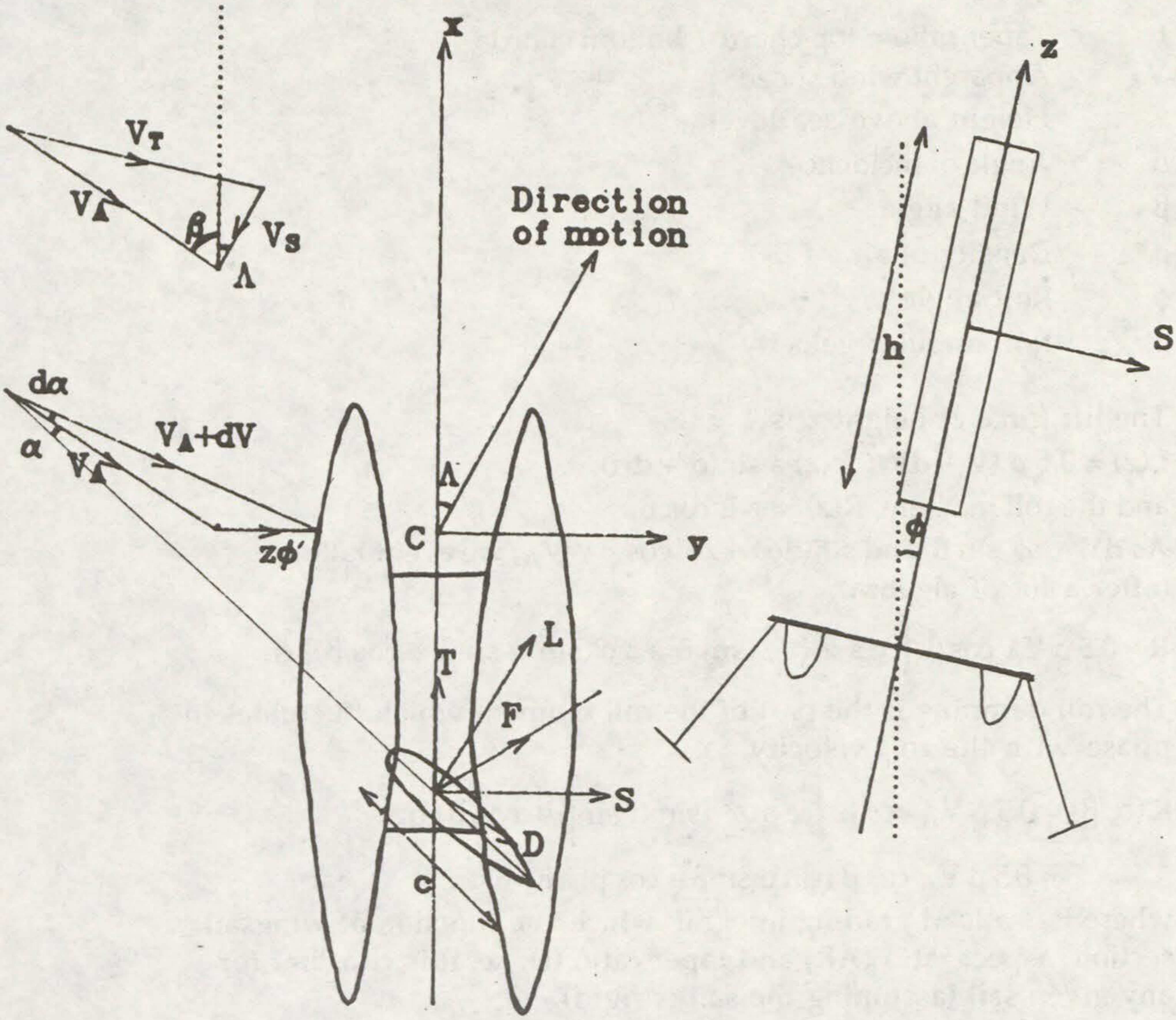


Figure 1 - Definition of symbols

a	Lift curve slope = $(dC_L/d\alpha)$
AR	Aspect ratio = h / $\hat{c}$ = height / mean width
c	Chord (width of sail)
$\hat{c}$	Mean chord
C_L	Lift coefficient = $L / 0.5\rho V_A{}^2 \hat{c} h = a \sin \alpha$
C_R	$R' / 0.5\rho\ V_A\ \hat{c} h^3$
D	Drag force
E	Load grading integral
h	Span (height of sail)
L	Lift force
R	Roll moment
R'	Roll damping moment

t	Taper ratio = top chord / bottom chord
V_A	Apparent wind speed
z	Height above sea level
α	Angle of incidence
β	Wind angle
ρ	Density of air
ϕ	Roll angle
ϕ'	Roll angular velocity

The lift force at height z is
$L(z) = 0.5\,\rho\,(V + dV)^2\ c(z)\,a\,\sin(\alpha + d\alpha)$,
and the roll moment, $R(z) = z\,L\cos\beta$.
As $dV \approx z\phi'\sin\beta$ and $\sin(d\alpha) \approx z\phi'\cos\beta / V_A$, we eventually get (after a lot of algebra):

$$R \approx 0.5\,\rho\,V_A\cos\beta \int c\,a\,z\,\{V_A\sin\alpha + z\phi'(\sin\alpha\sin\beta + \cos\beta)\}\,dz$$

The roll damping is the part of the roll moment which fluctuates in phase with the roll velocity, i.e.

$$R'(\alpha,\beta) \approx 0.5\,\rho\,V_A\cos\beta \int c\,a\,z^2\,(\sin\alpha\sin\beta + \cos\beta)\,dz$$

$$\approx 0.5\,\rho\,V_A\cos\beta\,(\sin\alpha\sin\beta + \cos\beta)\,\hat{c}h^3\,E,$$

where E is a load grading integral, which is a function of wingsail section, aspect ratio (AR) and taper ratio (t), i.e. it is constant for any given sail (assuming the sail is rigid).
The roll damping can be written as a roll damping coefficient,
$C_R = R' / 0.5\rho\,V_A\,\hat{c}h^3 = \cos\beta\,(\sin\alpha\sin\beta + \cos\beta)\,E$
All this becomes much more complicated when you include drag, wind shear, twist, etc., which add other small terms to C_R.

As can be seen from Fig. 2 the roll damping will always be very low in a beam apparent wind, where the roll damping depends mainly on drag. An efficient high-lift-low-drag sail will have very little stability in a beam wind, or even negative stability (which may cause capsize, since the hydrodynamic part of the stability is also low in a beam sea). Racing yachts are not usually designed to sail in beam apparent winds, but they can't always avoid them. A sail with higher drag would give more stability, and there comes a point where the speed benefit from the damping outweighs the speed loss from the drag, but this really only applies if you spend a lot of time sailing in winds near the beam.

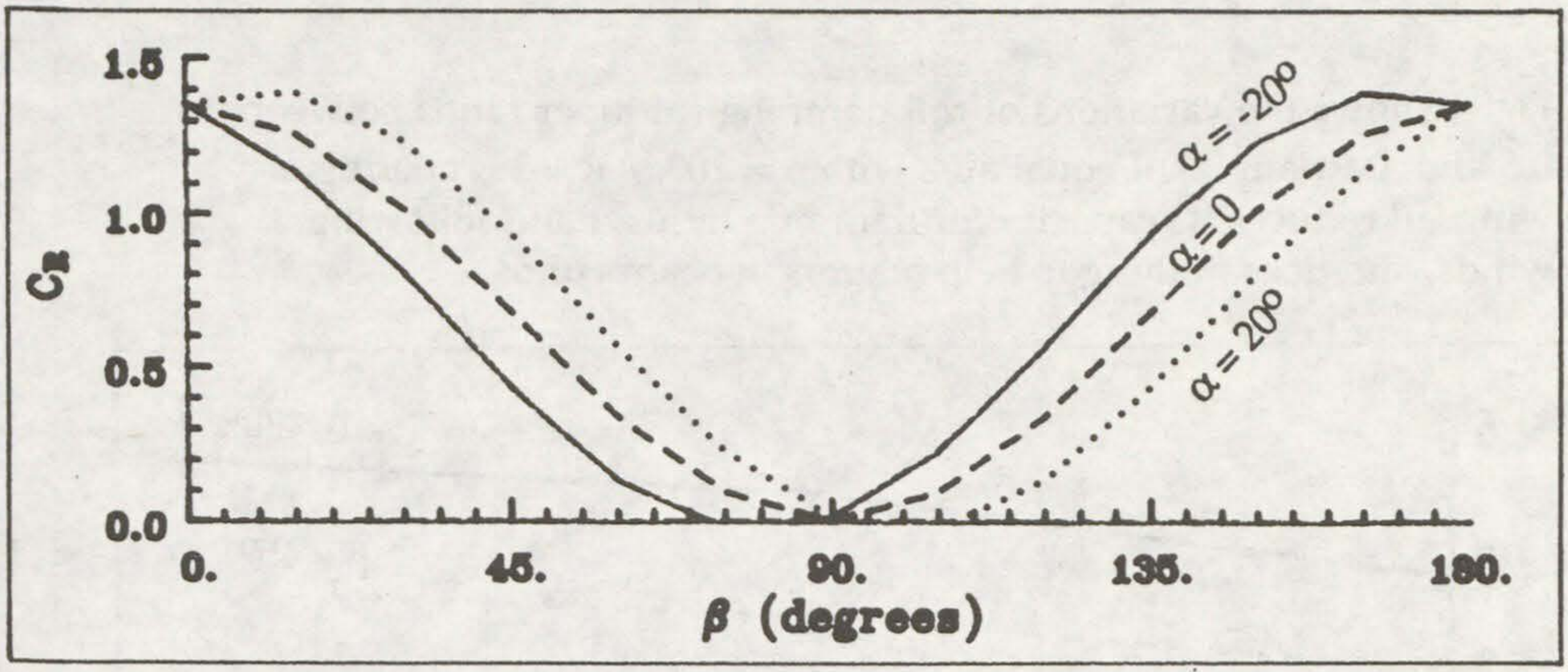


Figure 2 - Variation of C_R with β and α, AR = 3, t = 0

The roll damping coefficient is shown in Fig. 2 for apparent wind angles $0 < \beta < 180^o$ and sail angles, $\alpha = 0$ and $\pm 20^o$, and it is seen that negative damping will always occur in a beam wind (near $\beta = 90^o$). The negative damping condition can be avoided by ensuring that α is positive for $\beta < 90^o$, negative for $\beta > 90^o$, and zero for $\beta = 90^o$. Notice that maximum thrust, corresponding to the $\alpha = 20^o$ line, gives large roll damping for $\beta < 90^o$ but low damping for $\beta > 90^o$, where a compromise will be needed to get maximum speed.

The effects of aspect ratio are shown in Fig. 3 for triangular sails of AR = 2, 3 and 4, all of the same area. Increasing the aspect ratio gives larger roll damping in head and following winds, as the induced drag is lower and the moment arm is higher. However, in beam winds there is still the same problem due to low drag.

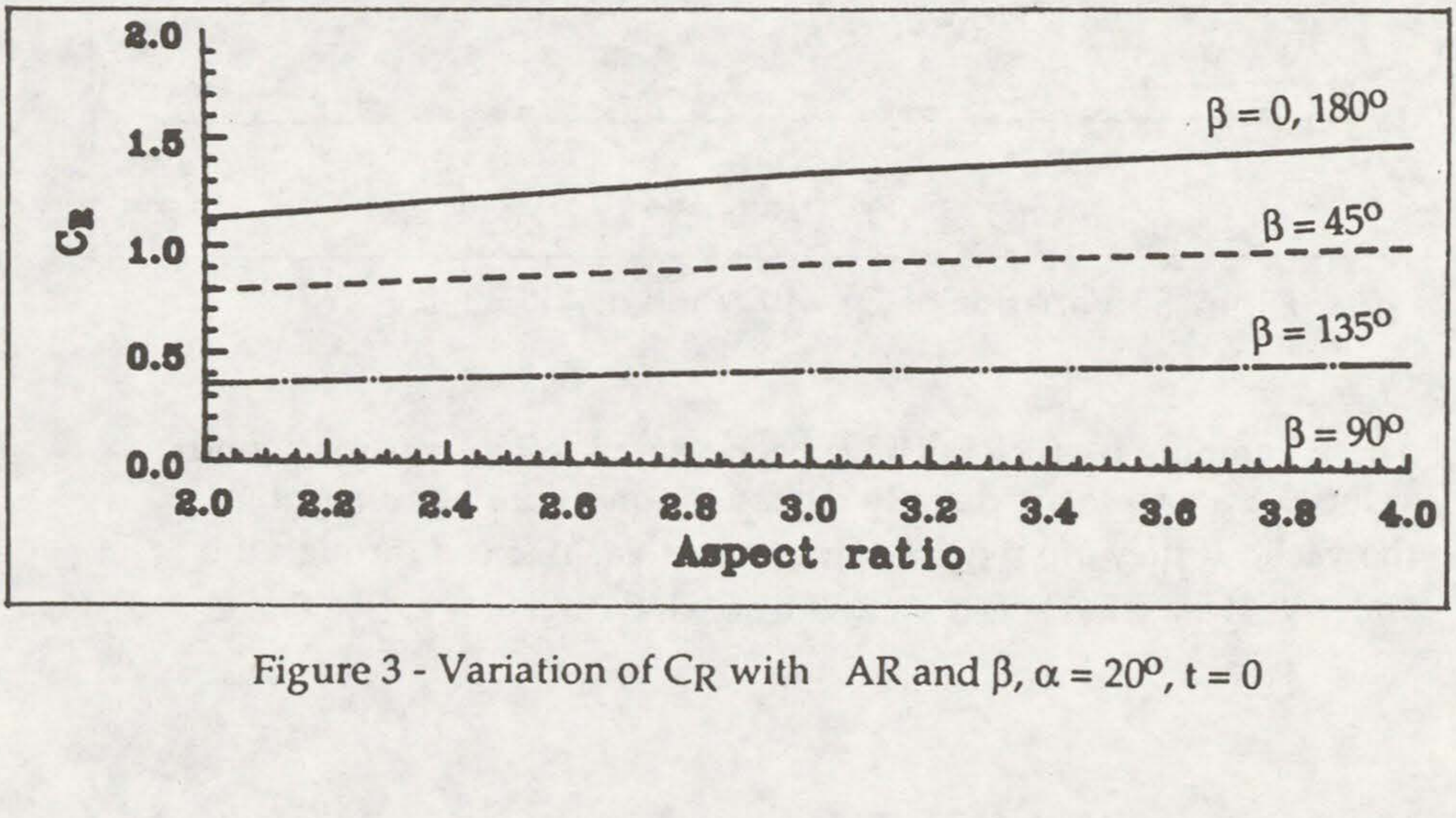


Figure 3 - Variation of C_R with AR and β, $\alpha = 20^o$, t = 0

Fig. 4 shows the variations of roll damping for taper ratios between 0.5 and 0 (triangle) of equal area with $\alpha = 20^o$, AR = 3. Tapering a wingsail reduces its capacity for damping in head and following winds, and does nothing to help matters in beam winds.

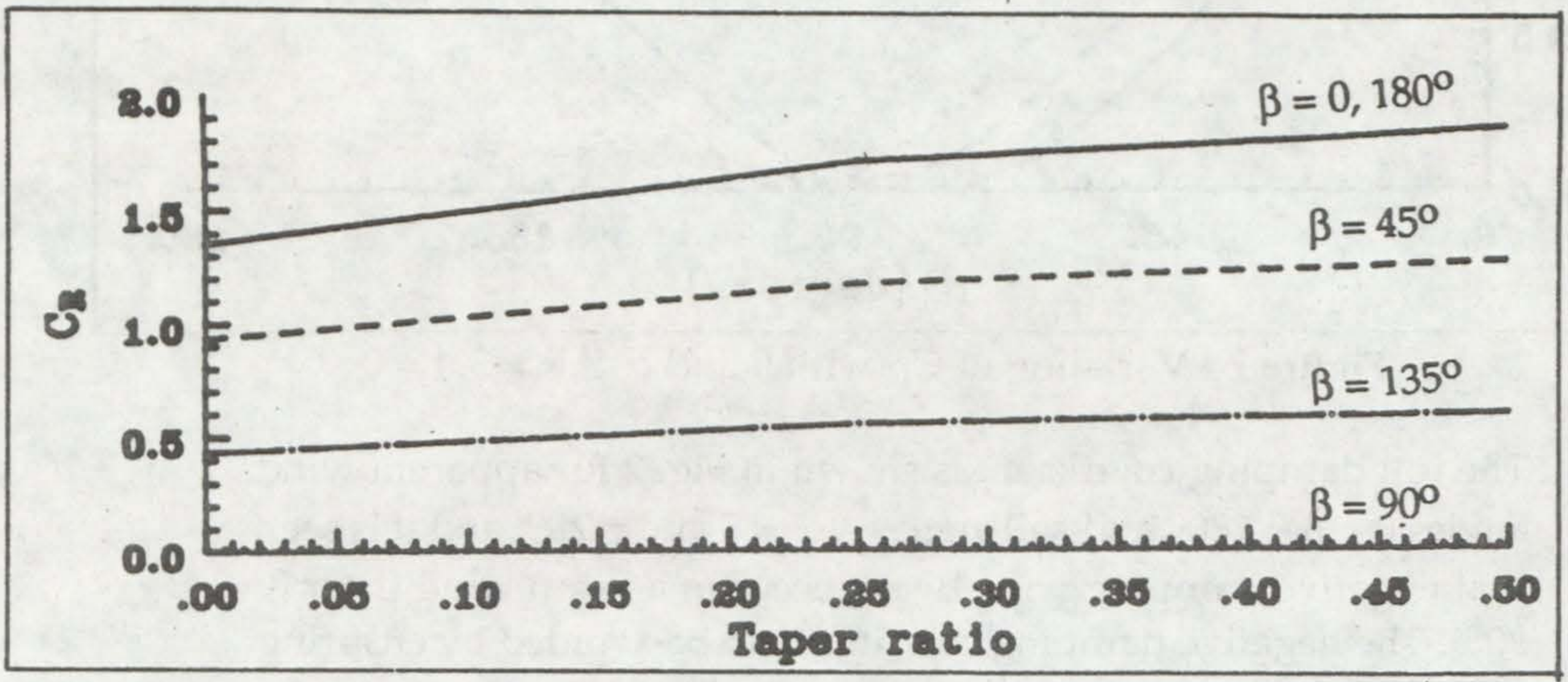


Figure 4 - Variation of C_R with taper and β, AR = 3, $\alpha = 20^o$

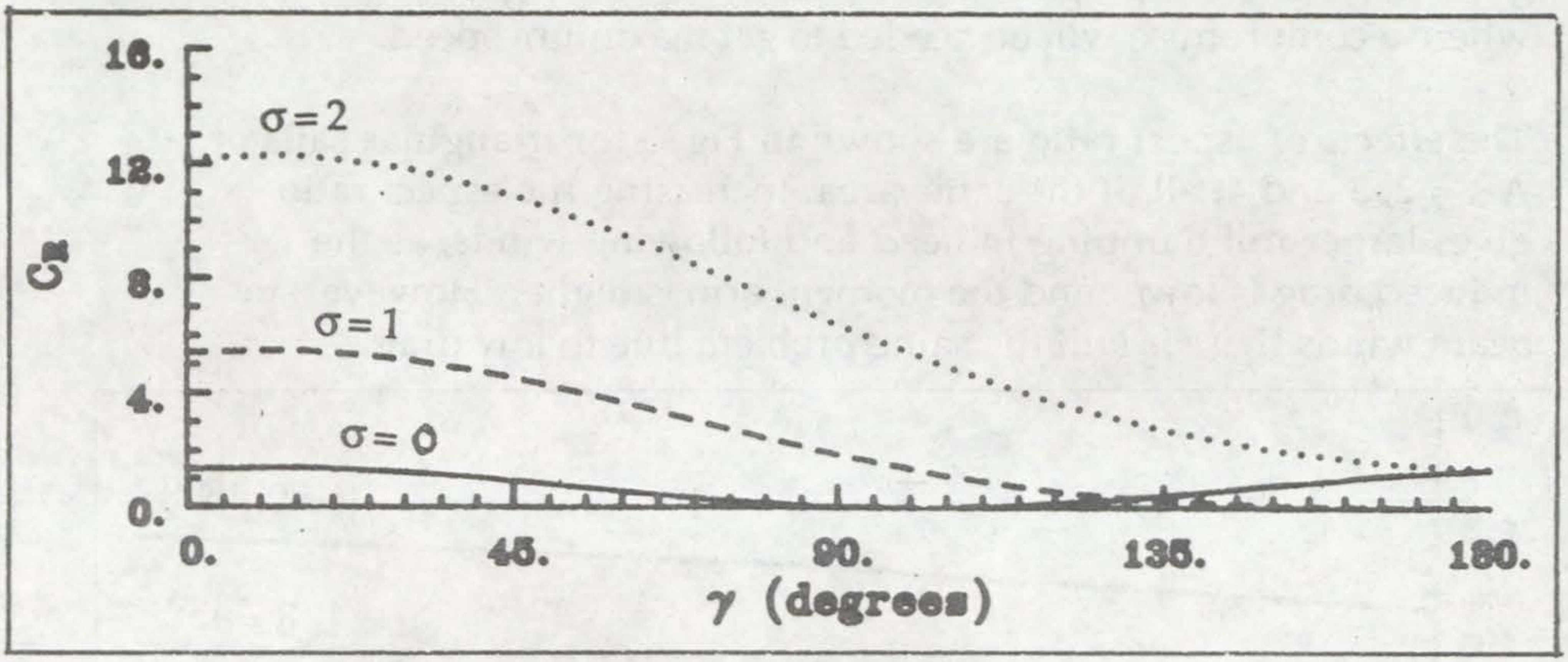
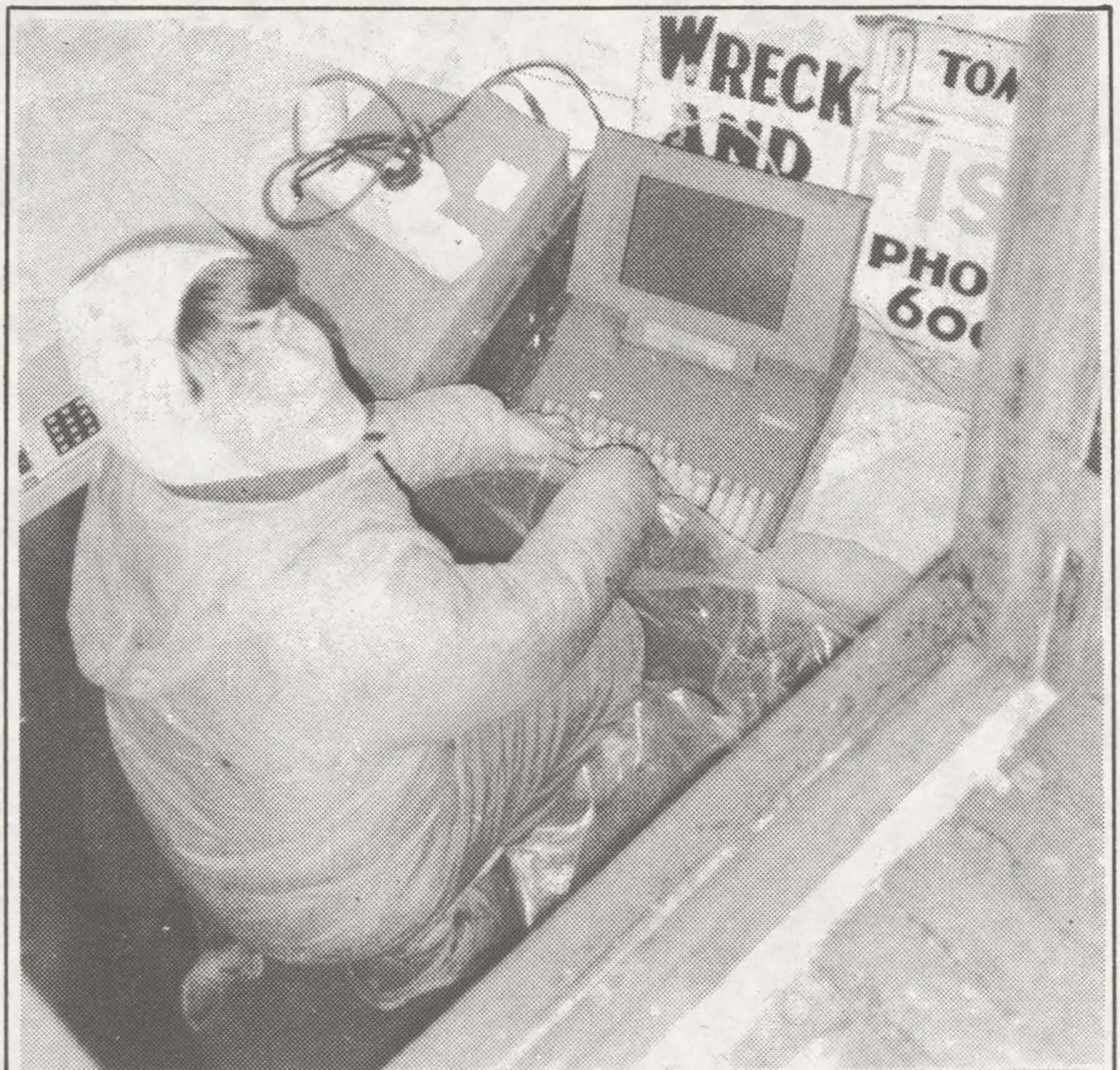


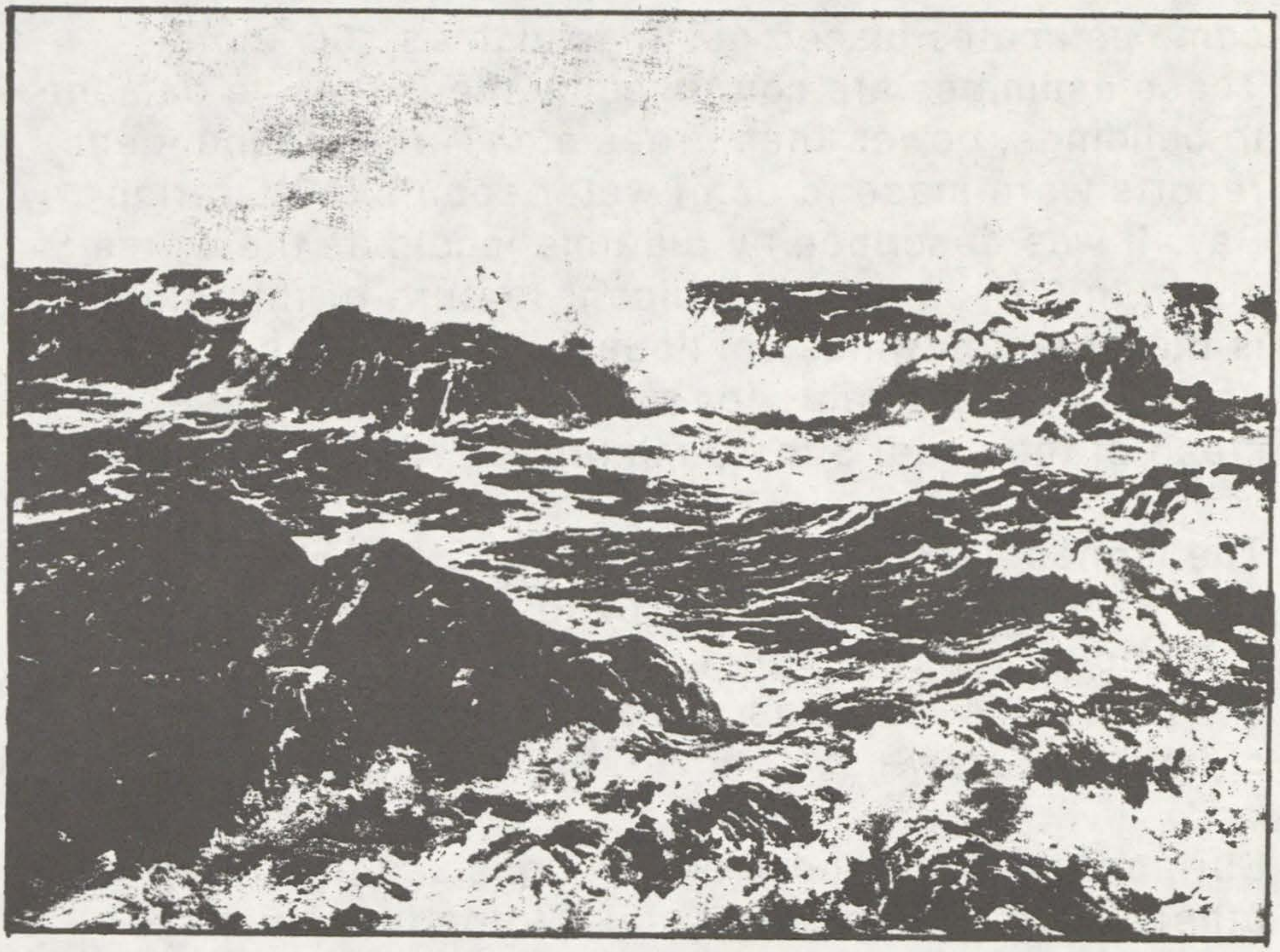
Figure 5 - Variation of C_R with γ and σ, AR = 3, $\alpha = 20^o$

These damping coefficients have been related to the apparent wind velocity V_A and so are directly related to conditions as seen from the yacht. If they are required in terms of yacht speed through the water V_S, true wind speed V_T and true wind direction γ, (see Fig. 1) then a re-plot of the results in Fig. 2 for various ratios of $V_S/V_T = \sigma$ is shown in Fig. 5. Roll damping can become negative in quartering winds for low values of σ, but at racing speeds (higher σ), it should remain positive except in a following wind.

For optimum performance, it is necessary to combine the yacht's hydrodynamic roll damping with this aerodynamic roll damping. Hull roll damping derivatives are usually obtained from experiments. Unfortunately, there are still often large discrepancies within the published data for roll derivatives even for similar hull shapes and in a given set of experiments with a single hull.
Therefore, at present, the optimum combinations of sail and hull must be found be measuring performance on the water, not by calculating from equations. It is the combined effect of the sail and hull acting together that matters.



Fiona Sinclair "fishing around" for some data



TRAILERTRI CLUB OF QUEENSLAND

Storm Report - 6 January 1985

On Sunday 6 January 1985, following completion of racing on the second day of the inaugrual Australian National Trailertri Titles, a storm of extreme ferocity struct the southern part of Moreton Bay. Windspeeds at Wellington Point were estimated between 70 and 85 knots. Manly Coastguard reported that their windspeed meter registered its maximum of 75 knots, before disintegrating. Windspeeds in the open bay would be in excess of this and are estimated at 80 to 90 knots -

some estimates placed gusts as high as 100 knots. These estimates are confirmed by the extensive damage to buildings, power lines, trees etc. Three independent reports were made to us of water spouts in Waterloo Bay. It was described by old time locals as the worst storm in 30 years. A significant feature of this storm is that the high winds continued unbated for a considerable time - probably for about 30 to 40 minutes, instead of the usual 5 to 10 minutes.

The highest level on the Beaufort Scale is Force 12 - Hurricane Force - with windspeeds of 64 + knots. There is no doubt that the storm we experienced was well in excess of this, and was therefore a mist extreme test of boat and crew.

During the storm, one Trailertri capsized and three others were "rolled over" whilst folded - one in the anchorage and two others while on their trailers. Six other Trailertris survived the storm whilst on the water in a sailing configuration.

LESSONS LEARNED

1. Don't try to fight a storm by trying to sail into it. Either run offbefore it under bare poles with a touch of centreboard down to the helmsman (if you have enough searoom), or preferably, drop all sails, raise the centreboard and rudder, and lay to the biggest anchor (or anchors) you have with all the chain and line you've got. Don't forget sheetlines can be used as anchor line. A further suggestion is to slide a weight down the anchor line to help keep the anchor as near to horizontal as possible. The chain from your spare anchor could be used, or a diver's belt, etc. Some wise skippers have a "pig" - alump of lead which can be shackled to the anchor line

2. Make sure your anchor bollard is of adequate strength and is securely through bolted. The bitter (inboard) end of the anchor line should be secured to a strong point. Some favour using one of the sheet winches, while others consider it should be permanently attached to a suitable point inside the anchor well. An eyebolt through the inner forestay chainplate, seems most appropriate.

3. Make sure your ground tackle is adequate. Nothing less than a 16lb spade (Danforth) anchor with 6m of chain and 40m of 12mm rope should be considered adequate for Moreton Bay. Other localities should allow an anchor line of at least 5 times the depth of the deepest water likely to be encountered, plus at least 6m of chain with an anchor suitable for the bottom conditions. A spare anchor line (a piece of slit polythene tubing) where it passes through the fairlead is a good idea.

4. Close mesh wing nets are seen as a contributing factor in the capsize and as a problem by some other yachts which had them. The designer has previously strongly recommended that they NOT be fitted. Despite what some sailmakers and others may tell you, close mesh wing nets are dangerous. This Club therefore strongly recommend that Trailertris be fitted only with open mesh wing nets.

5. In extreme conditions, consider cutting the wing net cords as an option (particularly if you've ignored the previous recommendation). The other option is to get as much crew weight as possible into the wind-

ward net, but sometimes conditions may be too severe for this.

6. Flares should be in a waterproof container.

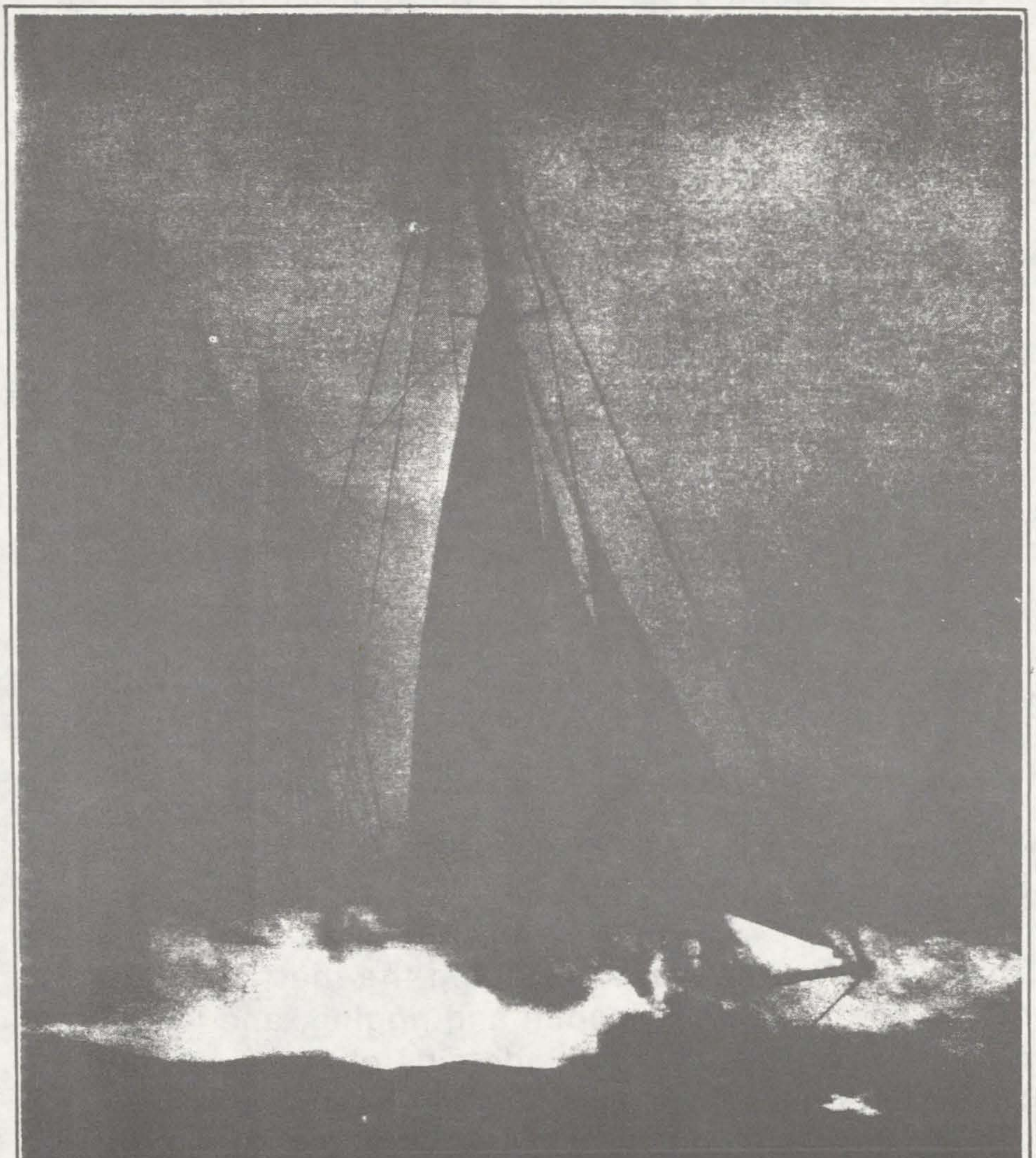
7. All hatches should be able to be positively secured from the outside.
Hatch hinges must be sturdy. Plastic hinges on outside hatches are useless. (Save them for the galley!). TRINITY lost several hatches, including her pop top and aft cabin hatch, and much valuable gear. This contributed directly to the capsize, as it caused the skipper to be fearful of pooping.

8. Don't be afraid of pooping! Trailertris do not sink! It's unlikely that you would take any significant amount of water on board, but if you do, it is uncomfortable rather than terminal.

9. The safest place is down below. Excess crew and passengers should be placed here, and under extreme conditions, after having done all that can be done topsides, this is probably the best place for the skipper.

10. Don't despair! The common thread through all this is the fact that no Trailertri suffered any structural damage to her hulls, and every skipper was impressed with their performance under the extreme circumstances. The skipper of TRINITY is of the opinion that the key factor in his capsize was his own inexperience Hopefully, this report will help to prevent any such future disaster.

A further word about the storm. Brisbane usually has one or two of these severe storms each summer, usually with a fairly localized path of severe damage. In some cases complete blocks of new brick houses have been completely demolished and literally blown away. A fun place at times is Brisbane. Unfortunately, this time, the Trailertri fleet was caught in that storm path, and we can only be very thankful that we got off relatively light.



Multihull Stability

In a most interesting example of collaboration between an American and a Russian, Hugo Myers (a catamaran designer from Virginia) and Jury Kruschev (a professor of ship science at the Nikolaev Shipbuilding Institute, Ukraine) applied ship theory of stability to catamarans and trimarans in various combinations of wind and sea. They were concerned that there had been a number of multihull capsize accidents in squalls and wave conditions, in which crew and yachts had been lost, and having developed a mathematical model to describe the rolling motion, produce recommendations to avoid future repetitions of such accidents.

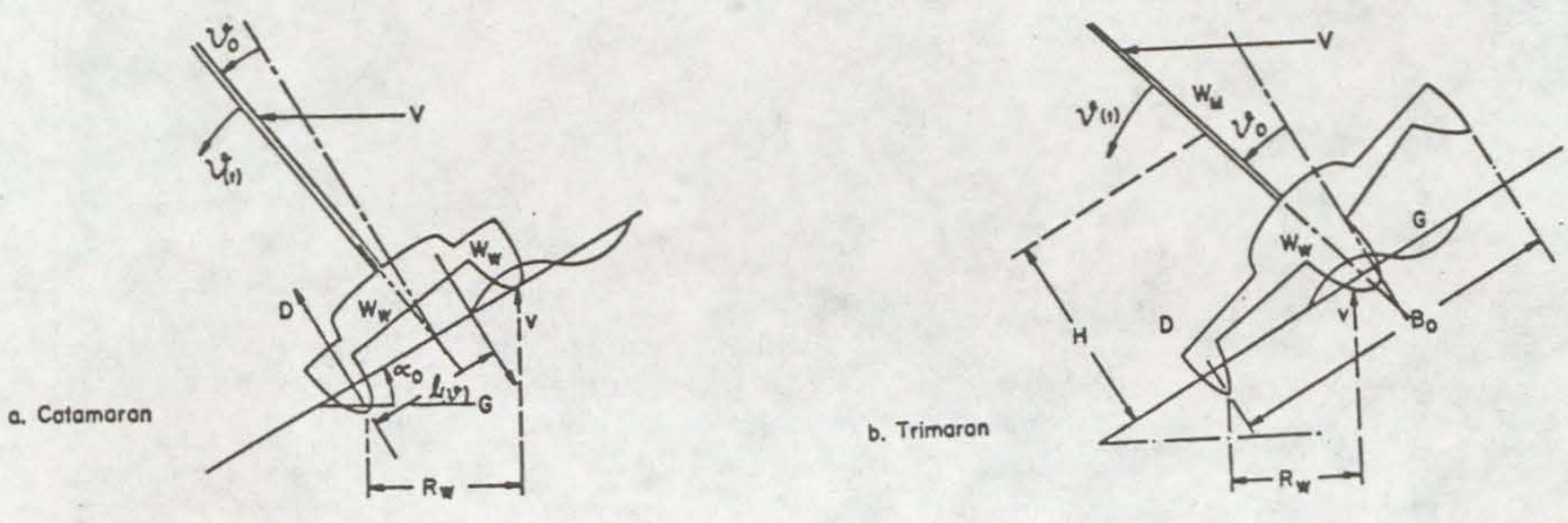


Fig. 1 Capsizing and righting forces on multihulls

The overturing moments, icluding the inertia of the rolling boat, the mast, boom, and rigging, and the wind moments on the sails and underside of the wing and hull, must equal the righting moments due to the hull, wing and crew weights.

In looking at this situtation it is seen that the trimaran suffers two disadvantages. Even under a normal press of wind the trimaran heels more than a catamaran. Also, because the leeward "ama" is closer to the main hull than the spacing between the two hulls of the catamaran, the lifting of the main hull causes a greater initial roll rate in the trimaran than the catamaran. When superimposed on to a wave face the trimaran is thus inclined at a greater angle than a catamaran. Furthermore, the trimaran has greater moment of inertia, an advantage when there are no waves, but once set into motion on a wave face, the inertia of the trimaran continues the roll until it becomes a capsize. This contrasts with the static stability of the craft, which is greater for the trimaran than the catamaran.

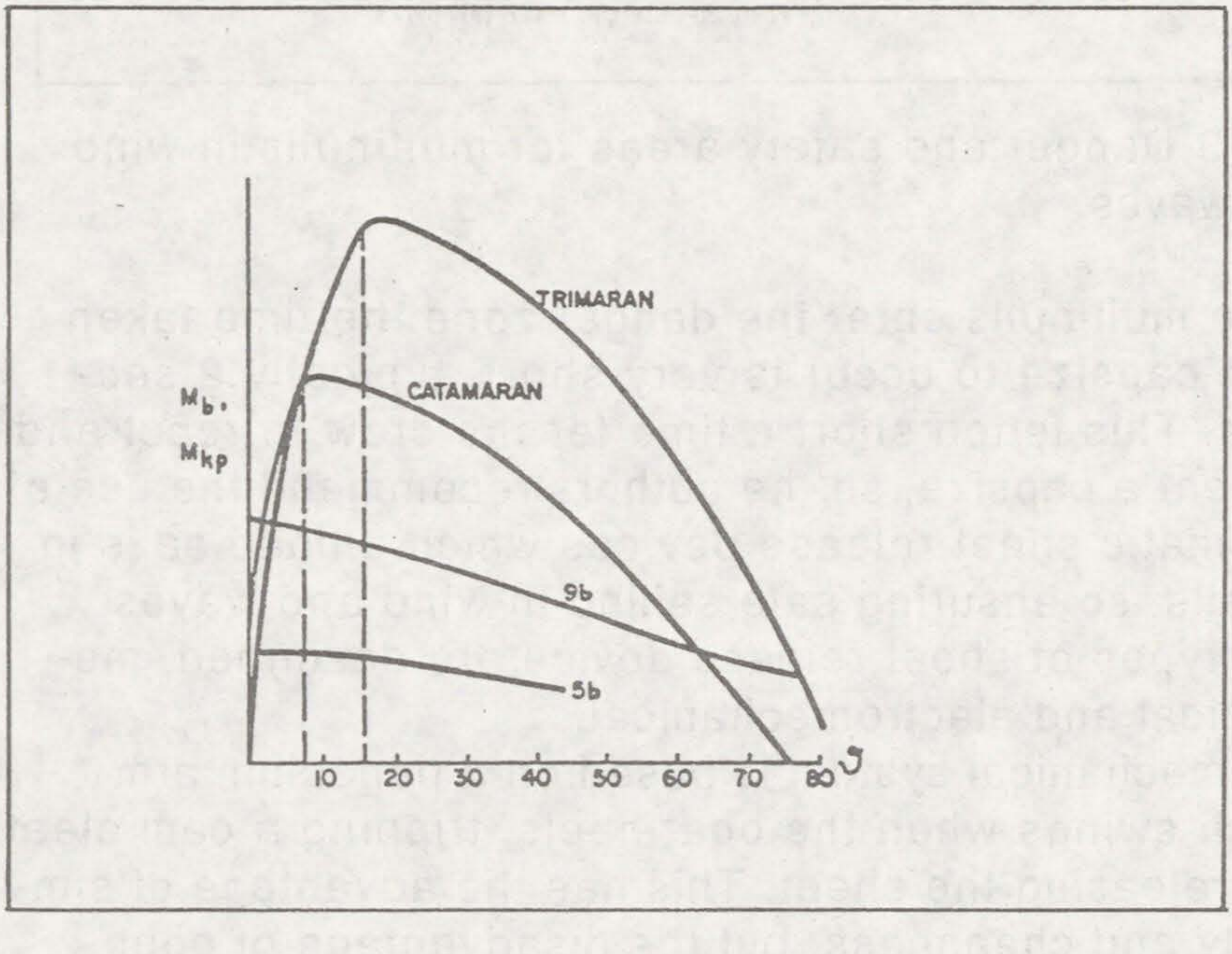


Fig. 2 Static stability of Multihulls

When wind and waves are taken into account a picture of the dynamic stability of the craft can be built up, and the danger area plotted for trimarans and catamarans.

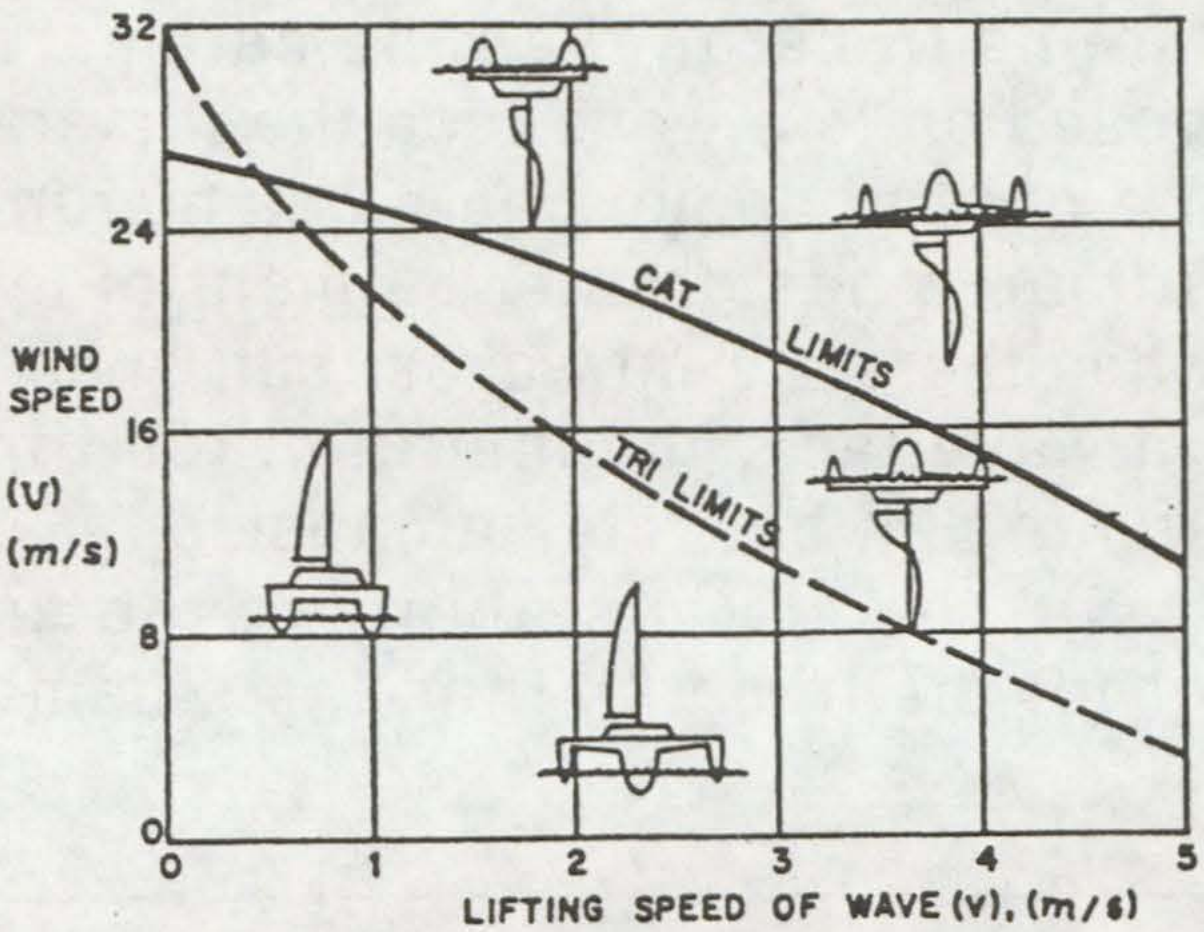


Fig. 3 Danger and safety areas for multihulls in wind and waves.

Once multihulls enter the danger zone the time taken for a capsize to occur is very short, typically 2 seconds. This is too short a time for the crew to react and prevent a capsize, so the authors recommend the use of automatic sheet release devices which unload sails in squalls, so ensuring safe sailing in wind and waves. Two types of sheet release device are described, mechanical and electromechanical.

The mechanical system is based on a pendulum arm which swings when the boat heels, tripping a cam cleat and releasing the sheet. This has the advantage of simplicity and cheapness, but the disadvantage of poor damping (hence lots of false alarms) and unsightliness.

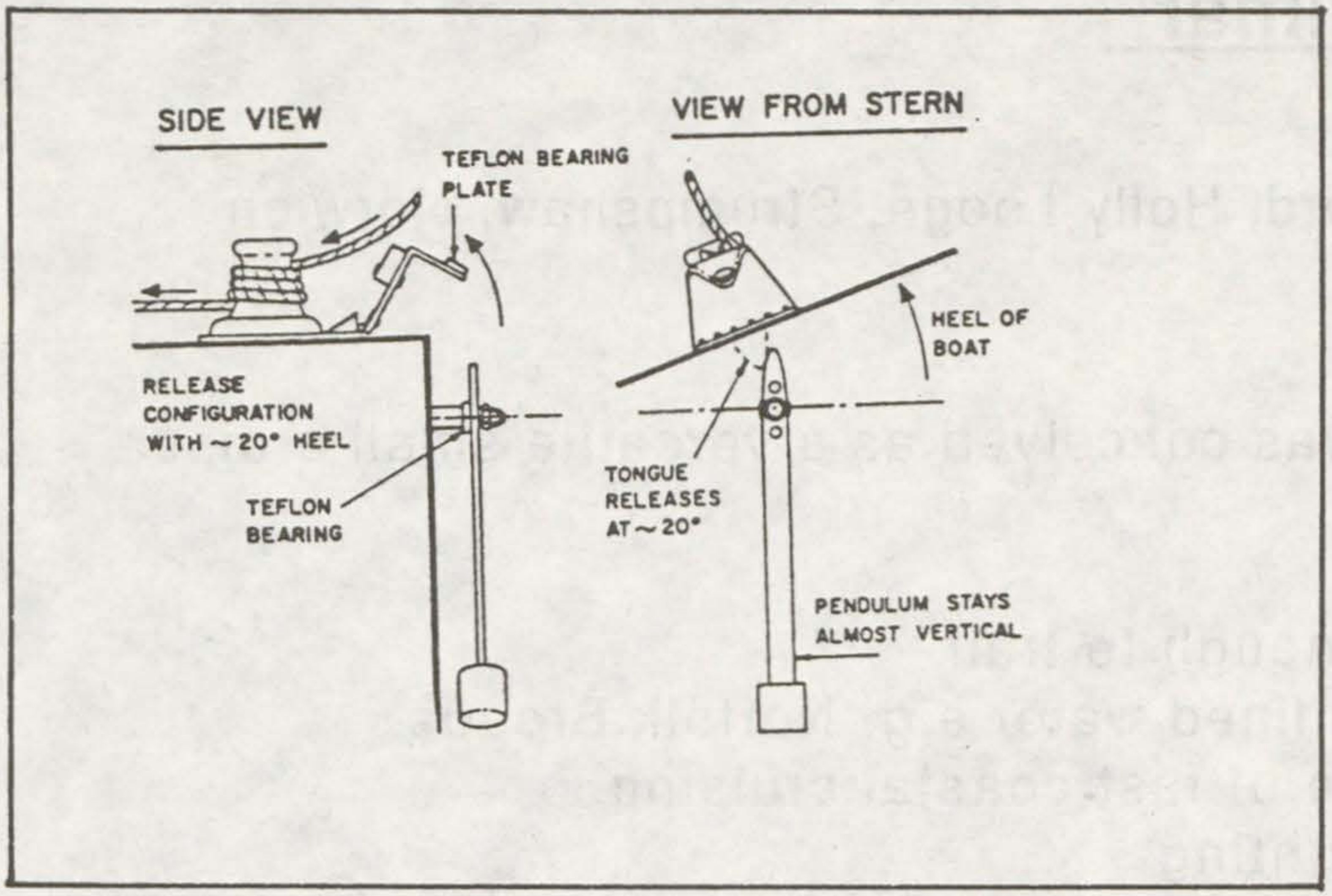


Fig. 4 Pendulum sheet release device

The electromechanical device relies on a mercury switch to release the cam cleat at a predetermined angle of heel. Despite high cost and reliance on battery power, this system is commended as having the following advantages:

Maximum angle of heel is independently adjustable for port and starboard tacks.
Sheets released in a fraction of a second.
Any number of sheets can be released.
Easily reset.
Will not foul sheets.
Operates from standard boat batteries.
Draws current only at the moment of release.
Release unit can be installed at any angle.
Overriding manual release buttons can be installed almost anywhere on the boat,
Audible warning can be fitted when sheets are released.
Easy Installation.

Shalimar

Paul Ashford, Holly Lodge, Strumpshaw, Norwich
NR13 4NS

Shalimar was conceived as a versatile small cruiser. Aims were:

i) Light enough to trail
ii) Suit confined water e.g. Norfolk Broads
iii) Capable of fast coastal cruising
iv) Self righting
v) Should not catch floating weeds, nets etc.

The idea was a lightly ballasted centreboard boat to suit (i) and (ii), to be used as a vehicle for stabilising foil experiments which if successful would provide power to carry sail in the stronger winds expected at sea. She was launched as a monohull in June 1986 and has been sailed for two seasons on the Norfolk Broads and rivers where she is fast, close winded and a delight to handle. Even with some inside ballast she needs reefing early compared with other cruisers of comparable length, but is then still fast and weatherly up to Force 5.

In 1987 I built a 1/8 scale model, with radio control of steering only, and started model foil experiments. The model statistics and results given below are all scaled up to prototype equivalant i.e. model test wind and boat speeds are multiplied by the square root of 8.

Prototype and Model Statistics

Hull length 23'-6"

Waterline length	22'-3"
Beam	7'-3"
Draft	1'10"/4'3"
Beam over foils	24'-0 (over square!)

Sail Areas Square feet

Main 140 Reefed 104, 69,38
Genoa 137 Working jib 63. Storm jib 27

Weights

	lb	DLR	Bruce Nos	
Hull	1300	(3)	(4)	
Ballast keel and centreplate	610		M & WJ	Main & Genoa
Spars, rigging, sails	110			
Cruising equipment (1)	580			
Inside ballast or foils	240			
	2840			
Crew and gear (2)	750			
Prototype total	3590	145	.93	1.09
Stripped, 2 crew	3000	122	.99	1.15
Model with foils and keel	3800	154	.91	
Model and foils, no keel	3150	128	.97	

(1) Anchor, warps, outboard, cooker, mattresses, sea toilet, fuel, water, battery, etc.
(2) 5 day-sailing or 3 cruising.
(3) Displacement length ratio $= \Delta/(0.01\ L)$ where Δ is in tons and L in feet.

4) Bruce No . = As $^{1/2}$ / W$^{1/3}$
where As = sail area in sq. ft. and
W = displacement in lbs.

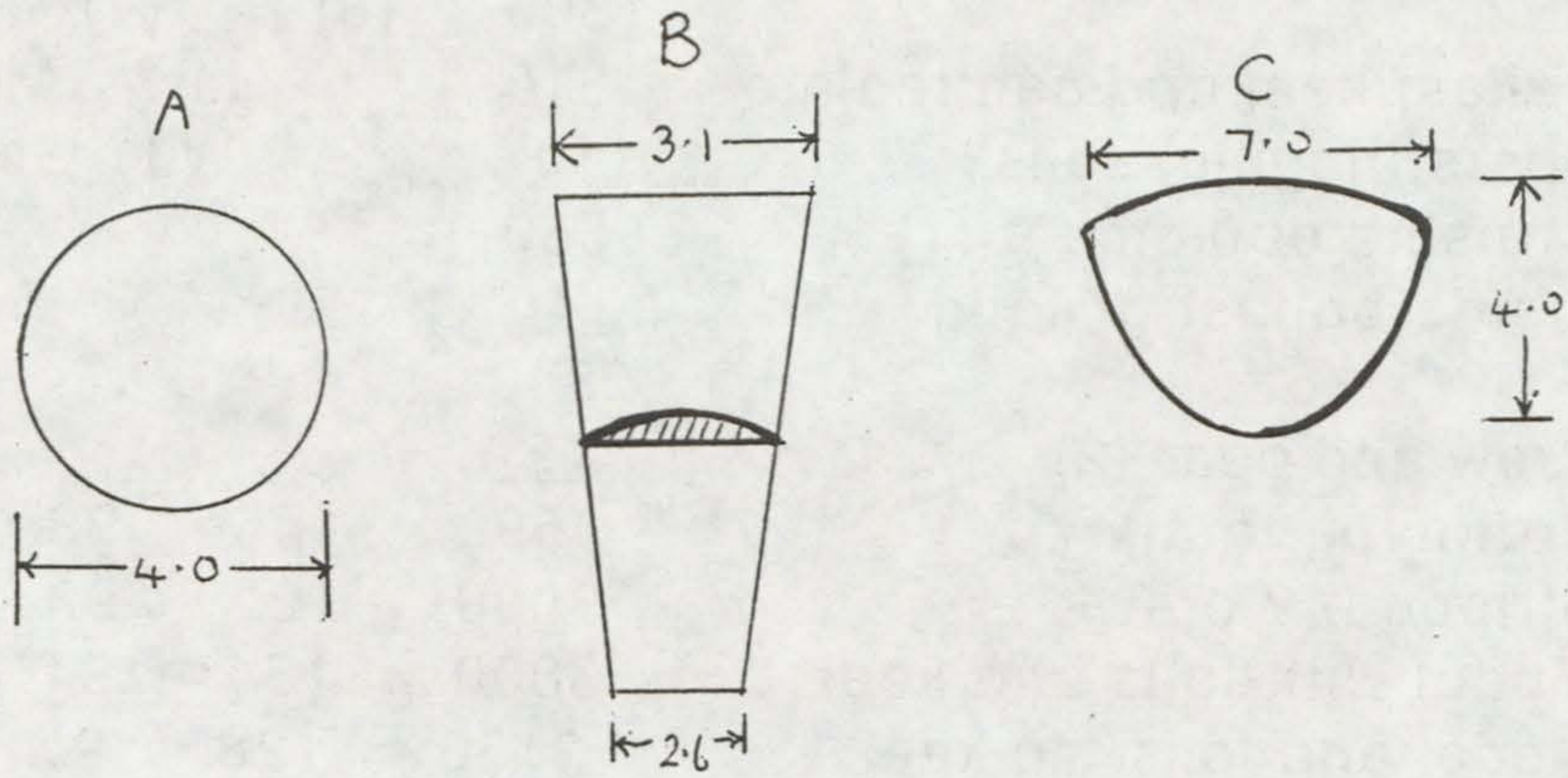
Keel Areas

Ballast stub	5.0
Centre plate	4.4
	9.4

Foil Areas

A	12.6
B	16.4
C	18.7

Foil Dimensions (ft.)



Foil Folding

My original hope was that foils could be rigidly attached to arms, each
with two hinges at the boat, and operated by fore and aft lines as Figure 1. But to stow adequate foil areas I had to introduce hinges between arm and foil and two extra parallel motion control lines (see photos). This gives the advantage that foil fore and aft position and toe-in are readily adjusted, and some resilience in case of collision.

Model Tests

I use three test tanks, firstly my bath for ballasting to correct trim and roll stability, also contemplative foil waggling. Next I have to thank my neighbour for use of his swimming pool, for righting tests, towing tests and WAK (Wrap Around Knockdown) tests. Reading of Tony Marchaj's model tests of yacht capsize by waves made me think. Shalimar looked vulnerable with her light displacement, low ballast ratio, and a negative righting moment beyond 135 degrees heel. Would foils help, or without way on be driven under, trip and precipitate a capsize? My WAK test is intended to crudely simulate a breaking wave striking a stationary craft beam on, and consists of securing a cord to the chainplates, wrapping it right round the hull and applying a smart horizontal pull beam on at deck level. With plate up or down the monohull was easily pulled over, moving only half its beam sideways before the mast hit the water. With foils (A and B tested) a 90 degrees capsize was quite difficult. Capsize did not happen before the craft had been dragged two or three hull beam's sideways, and more often than not it slewed and shot off ahead or astern to escape capsize. My subjective guess is that it took four or five times as much work to capsize it with foils. I conclude that it would be much safer to lie ahull in a breaking sea with foils than without, always provided the structure is up to it. Not that I aim for this sort of sailing.

It was more likely to capsize if it shot off astern, and this was probably due to 12 degrees toe-in. It would be safer to use less toe-in, or leave the control lines slack or springy enough to allow automatic reversal of the toe-in when moving astern (a subject for more tests).

In the towing tests foils A and B both caught up floating leaves, and B made a lot of fuss. So I moved on to test tank three, a Norwich park boating lake, to sail with A and C.

So far I have sailed on four days. Wind strengths, by hand held anemometer, have varied from 5 to 40 knots, gusting to 50 (as full scale equivalent). Sail was varied between main and working jib (M & WJ) to three reefs and storm jib (M3 & SJ). Speeds were measured by stopwatch while pacing a 20 yard run.

As a mono-hull the model mirrors prototype performance well, but can make good some 10 degrees less close to the wind. As the wind rises and she is overpressed the rudder leaves the water and she luffs. With no crew to free the sheets control is lost until the puff eases, but it appears impossible to capsize by sail pressure in smooth water. With M3 and SJ she can just be worked to windward in 30 knots, gybing between tacks. With no crew to back the jib and this small sail area she will not tack. WJ and SJ are self- tacking, but the genoa cannot be and has not been used.

With foils extended and plate up the model handles beautifully, and can be tacked with certainty in winds up to 30 knots with M2 and SJ. She will always bear away and gybe without fuss. In light winds she is some 10 degrees less closewinded than the monohull, but the problem then is to get enough foil immersion; a crew would adjust the centreplate to suit. As the wind strengthens, windward ability becomes better than the monohull, with a much more upright and comfortable-looking ride. But she can be capsized. Usually if a gust drives the foil under it recovers, but if prolonged (with boom 30 degrees off centre and tight kicker) there is a slow capsize. A crew would have plenty of time to ease sheets. If capsized 90 degrees she turns until the mast is upwind, recovers and sails off on the opposite tack. Less often the mast is driven under and hits the bottom at 135 degrees, when she will turn slowly round the masthead and eventually right. Obviously some masthead buoyancy would be a good idea.

I tried removing the stub keel and centreplate. With M2 and SJ she was a little less certain in tacking, but sailed very well with M2 & WJ in 20 knots wind. She seemed more lively, no more prone to capsize, but no longer self righting. The interesting point is that the keel stub does not significantly change foil action, but using the plate does drive the foils under much sooner. She is a little faster without the keel, presumably partly due to reduced displacement and partly removal of drag. Without the rudder the foils could be set to self-steer to windward with or without the keel stub.

There is no obvious difference in speed between foils A and C, but the larger C leaves less wake and seems more difficult to capsize.

Sailing with A folded and C extended, when to windward C showed little tendency to hang onto the water and its only benefit seemed to be "striking out" weight.

The model's best recorded speeds (scaled up) so far:

Configuration

	Sails	Wind (kts)	Speed(kts)	V/ L
Centreplate, no foils	M&WJ	12 on quarter	5.0	1.06
Foils & keel stub	M2&SJ	35 on beam	6.3	1.33
Foils, no keel	M2&SJ	35 on beam	7.0	1.48
Foils, no keel	M2&WJ	25 on beam	7.0	1.48

The mono model is probably capable of 5.5 to 6.0 knots under the right conditions, so top speed gains are useful rather than dramatic.

This table estimates sail which could reasonably be carried in various wind strengths in sheltered water:

	M&WJ	M1&WJ	M2&WJ	M2&SJ	M3&SJ
Without foils	10	15	19	24	30kts
Foiler knots	15	23	28	36	45

Foil Geometry

Foils are set to be nearly submerged at 15 degrees keel, which allows some hull stability to be utilised while reducing wetted surface. The upright dihedral is 62 degrees, leaving an effective 45 degrees as the foil submerges. Fore and aft the foil centre should be close to the centreplate centre. A toe-in of 6degrees seems good, 20degrees kills performance.

Heeled 15 degrees, line of thrust intersects the centre line 7'-3" above waterline, or (perhaps more relevant) the vertical through the centre of gravity 8'-4" above the upright waterline. Compare with sail centres M & WJ 13'-10" above waterline, and M2 and SJ 11'-3" above waterline. The model is thus substantially under balanced-out.

It is interesting to observe that inclusion of the hull profile above waterline in the "sail area" would bring the overall centre of effort down to around balanced-out. Hull windage thus has a stabilising effect. But even a keel-less hull produces some leeway resisting side force (there is at least 10 degrees leeway when going to windward with foils) and this is destabilising. Perhaps these effects roughly cancel out.

10 degrees less dihedral would theoretically raise the thrust line 2'-6" at the centreline or 4'-0" on line of the intersection with weight, but increased leeway will then increase the hull and keel stub side force. Clearly there is room for more experiment.

What else can be done to reduce chances of capsize? Before sail pressure can be substantially relieved by heeling to say 45 degrees, several adverse things are happening:

(a) Strut drag slows the boat and reduced foil lift.
(b) With dihedral down to 15 degrees, the automatic incidence control by
side-slip becomes ineffective, with further loss of

lift.

(c) Stern rises, bow drops, losing positive incidence given by toe-in.

The answer to (a) is strut streamlining. For (b) and (c) as the foil submerges some new control should take over to maintain optimum incidence. Figure 2 shows a possible system, a bit like half an aeroplane. The hinges are needed to stow the foils, so they might as well do another job. This should maintain positive righting lift as long as there is forward motion, perhaps strengthening with submergence, right down to dihedral of zero or beyond. It may allow reduction of upright dihedral to get nearer balanced-out. Back to the workshop, bath etc! A canard (a sort of canted Hook system) might work better, but I cannot see it folding conveniently.

Summary

Likely benefits of foils on Shalimar are:

(a) Some speed increase, probably modest.
(b) A docile and responsive craft in stronger winds.
(c) Less keel, more comfort.
(d) Reduced danger of broaching or wave capsize.
(e) No downwind rolling, and a 24'-0" sheeting base for downwind sails.
(f) Self-righting from 90degrees and masthead buoyancy.
(g) No increase in mooring space.
(h) Still able to sail in light winds and narrow water with foils folded.

Their forward weight will reduce wetted surface.

Against, apart from some work and cost, she could be capsized. Unfamiliar type may be difficult to insure.

Acknowledgements

These foil tests have been entirely inspired by the AYRS. Perhaps the foil folding arrangements are new, and the demonstration that a modest ballast stub for grounding and self-righting is not incompatible with foils. All the major ideas have been developed by other members. Particular encouragement came from George Chapman's articles on models in AYRS 5 and 10, and the tests of Gerald Holtom's cruising foiler model in 1974, but also from many other contributors.

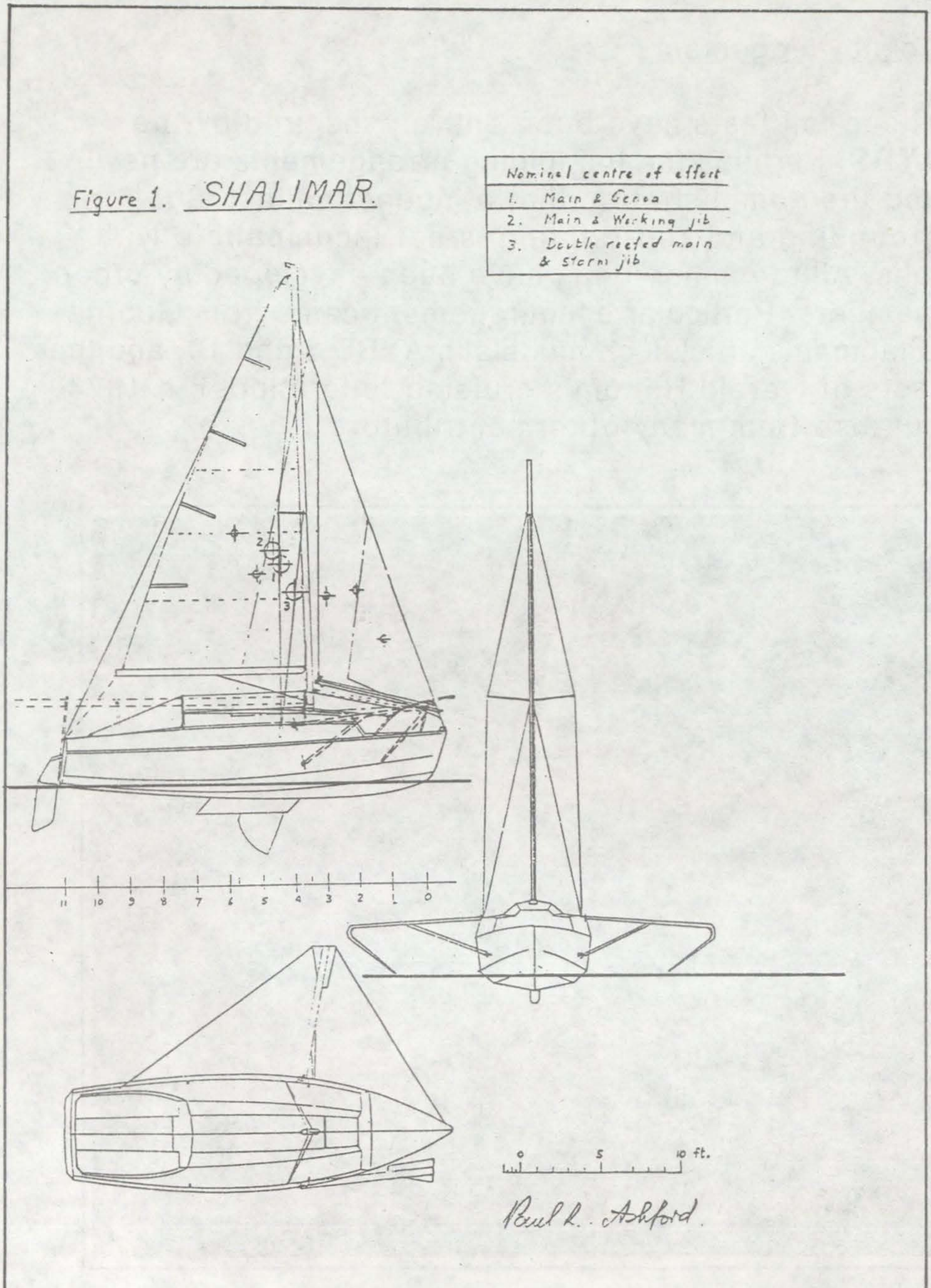
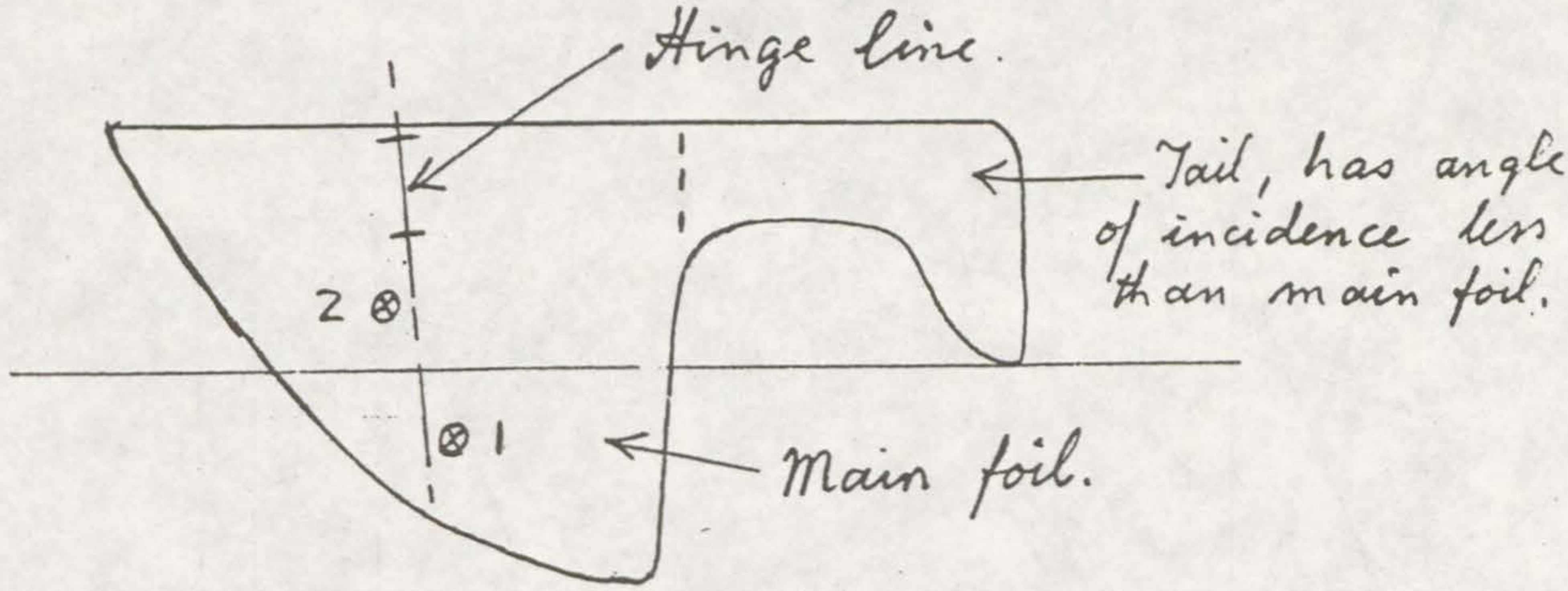
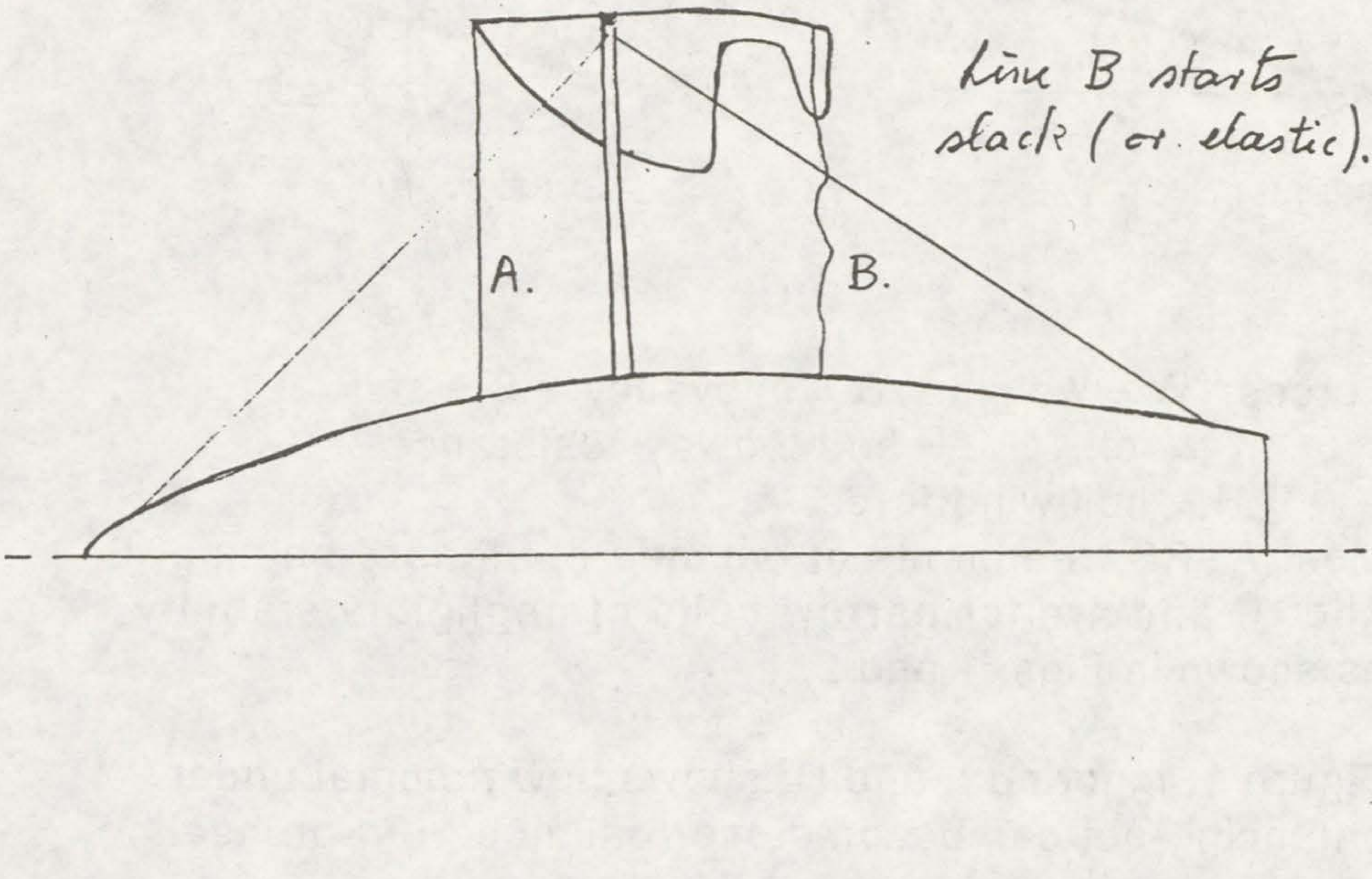


Figure 1. SHALIMAR.
Nominal centre of effort
1. Main & Genoa
2. Main & Working jib
3. Double reefed main & storm jib
11 10 9 8 7 6 5 4 3 2 1 0
0 5 10 ft.
Paul R. Ashford.

Figure 2 Shalimar





Centre of pressure of main foil:

1. Half submerged. Control line.
   A maintains small toe-in.
2. Fully submerged. Foil takes control to give optimum lift.

Some thoughts on Foiler Stability and Balance-Out

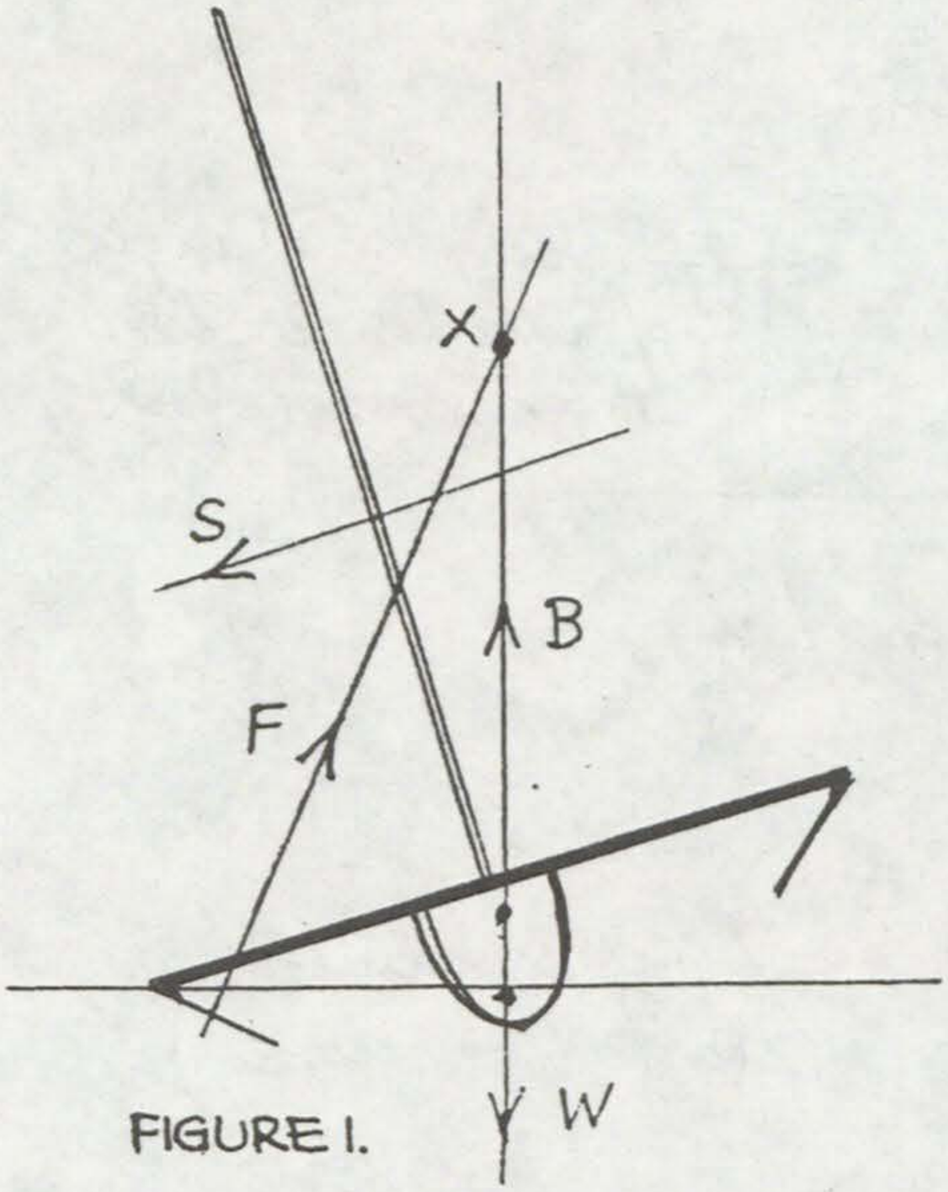


FIGURE 1.

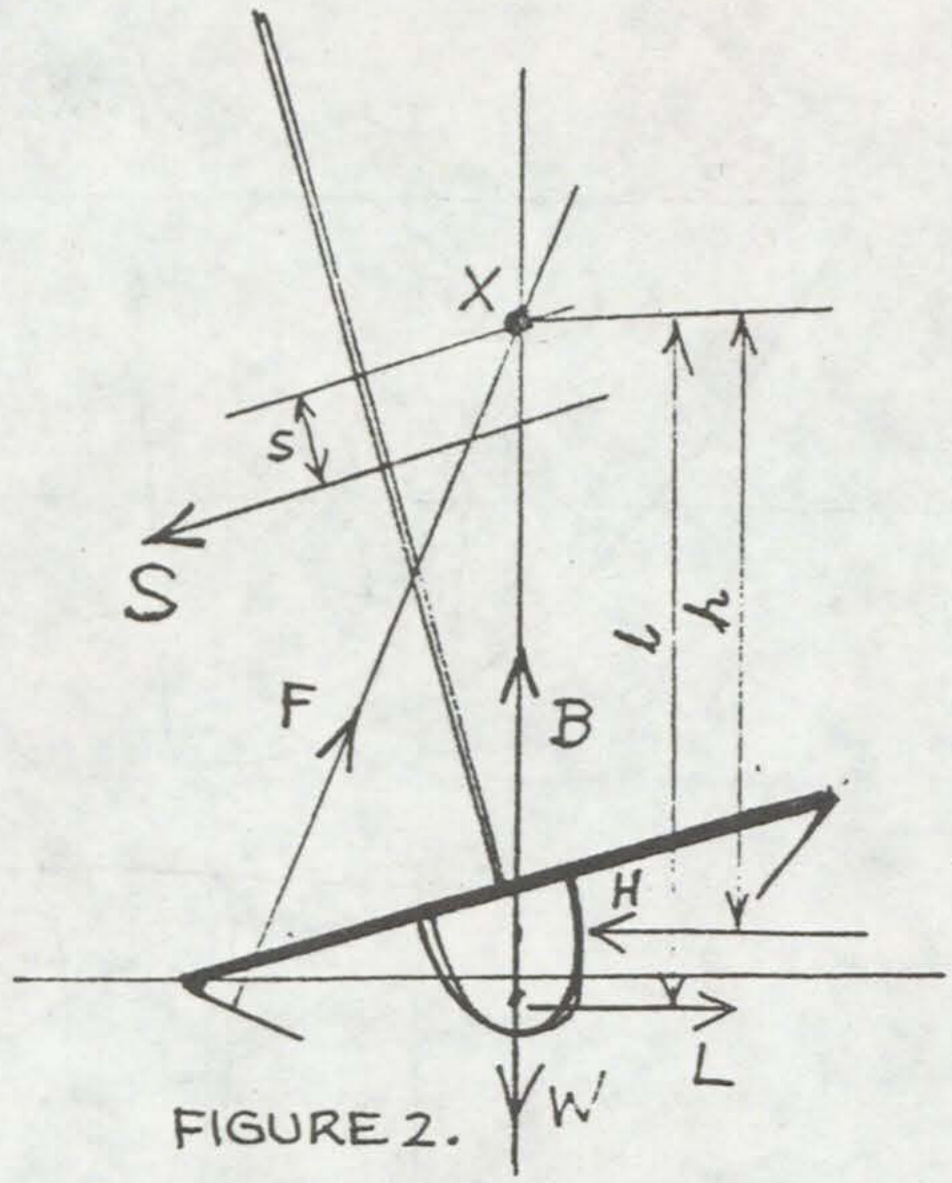


FIGURE 2.

Forces: W = weight. B = buoyancy. S = sail
F = foil. L = hull leeway resistance
H = hull wind force.

Most AYRS treatments of balance-out ignore heeling, L and H, and are for narrow hulls of negligible stability as shown in Figs. 1 and 2.

Figure 1, ignoring L and H, shows how nominal under balancing-out can become over balanced-out on heeling, considering moments about X.

Figure 2 brings in L and H. Tacking moments about X (which eliminated W,B & F).

	Righting		Capsizing
For stability	Ss + Hh	=	Ll

Note that if S passed above X it would be on the other side of the equation.

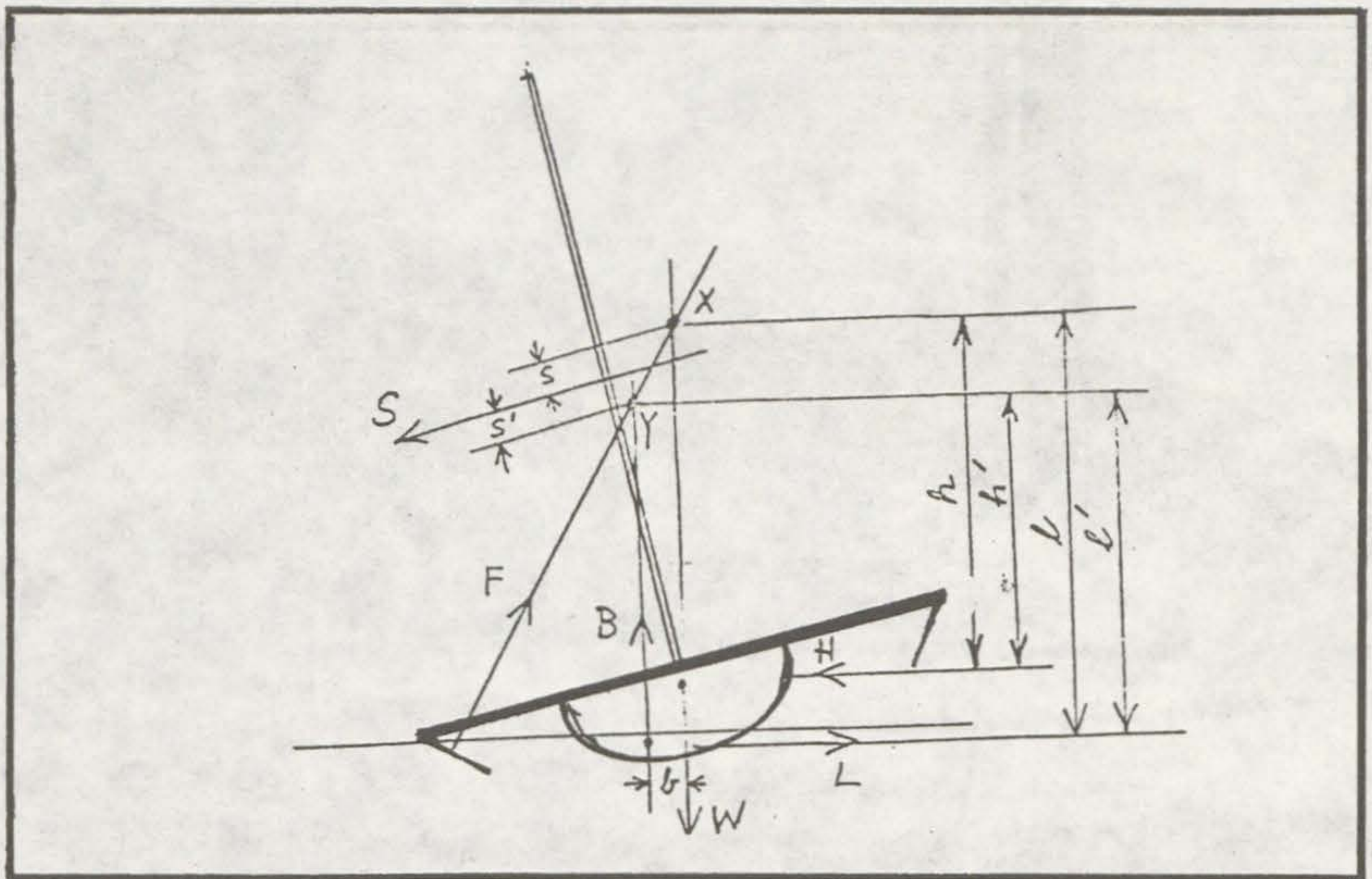


Figure 3 The wider hull

Figure 3 deals with the wider hull, where the transverse metacentre is above the centre of gravity.

Moments about X Righting Capsizing

For stability Ss + Hh + Bb = Ll

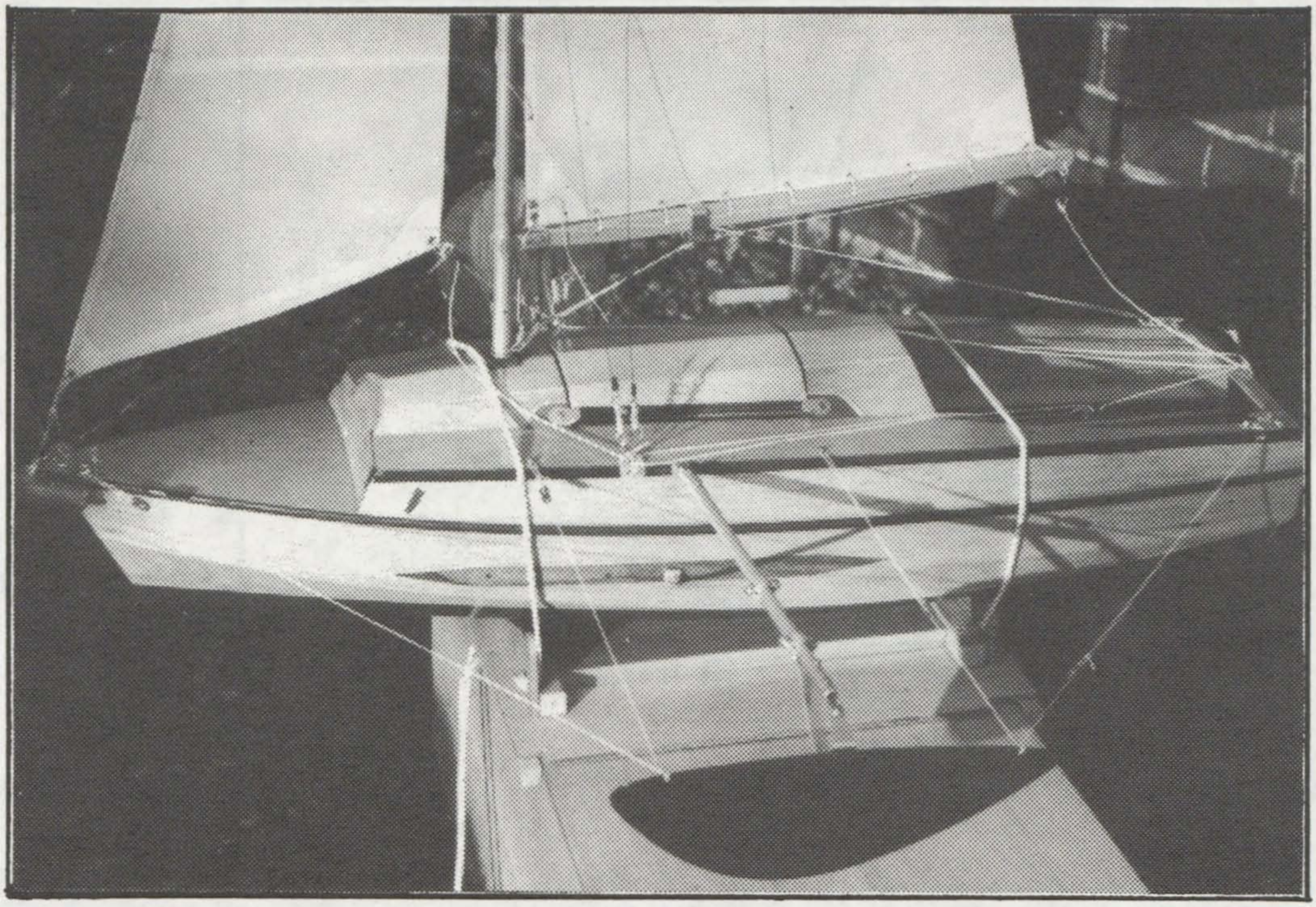
Since B differs from known W by vertical components of F and S, more conveniently:

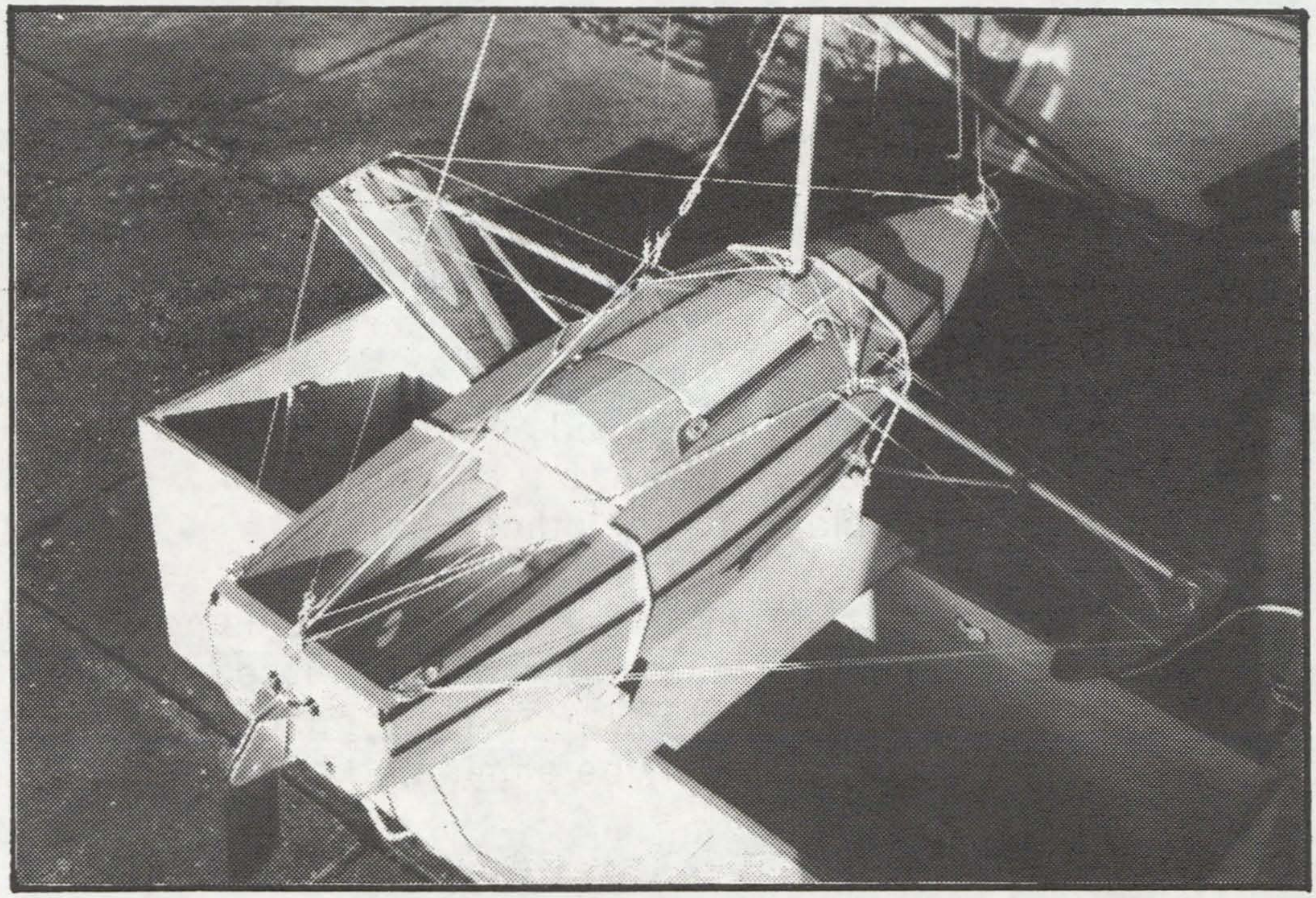
Righting Capsizing

Moments about Y Hh' + Wb = Ll' + Ss'

Note S has been placed on the side of the equation to suit the configuration as drawn, but depending on height of C of E could be on the other side.

L has a long lever arm and is seriously destabilising. It will be reduced by generous foil area. (therefore low leeway), possible by some toe-in (= fixed positive incidence), but can probably only be eliminated by variable incidence foils.





NOTES

NOTES

P U B L I C A T I O N S

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