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AMATEUR YACHT RESEARCH SOCIETY

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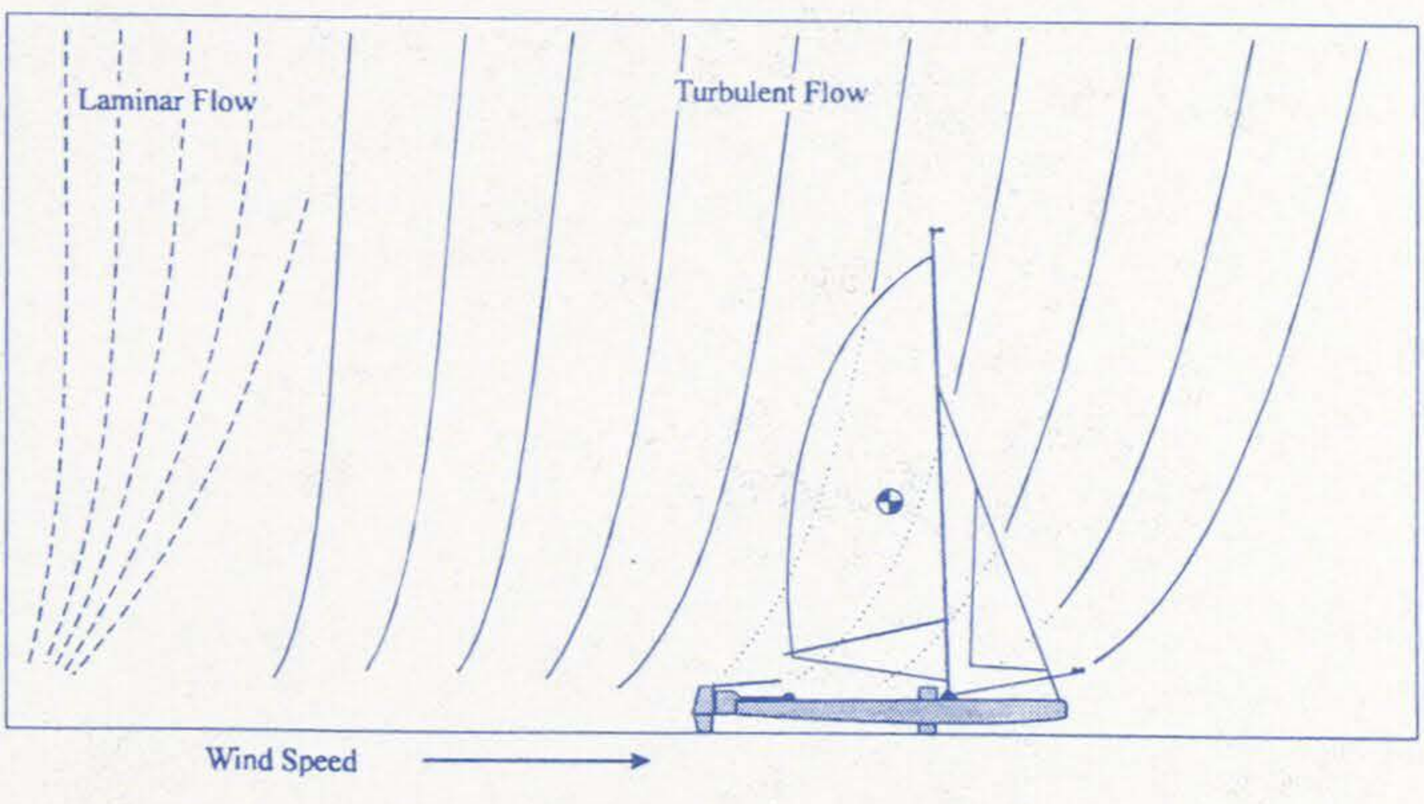
Instrumentation and Measurement of Performance



Edited by
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Instrumentation and Measurement of Performance

Edited by
George Chapman

Production by Tony Kitson

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Contents

Introduction

It is now over twenty years since Edmond Bruce, in 'Design for Fast Sailing' (AYRS 82), described a complete set of instruments for measuring the three or four parameters which describe - at the most basic - the performance of a sailing vehicle. 'Or four' because leeway, the fourth, is the most difficult to measure and seldom is, directly; yet it is as important as the others.

Bruce took the use of his sensors a step further than had been reported in AYRS writings before, by using electronic analogue devices to compute the derived parameters, in particular V_{mg} (speed made good to windward). His work paralleled that of the commercial manufacturers who, in the early 1970s were starting to offer on-board computation and display of V_{mg} and V_T, the true wind speed. Until recently there seems to have been no reported attempt by amateurs seriously to copy or improve on Bruce's work; only the professionals seem to have profited! Indeed, for whatever reasons, very few inexpensive speed and direction sensors have been available on the market, and one suspects that those have not sold sufficiently well to remain available; the wind and water speed sensors of Smiths Instruments are a case in point. Possibly because the small boat sailors they were aimed at did not bother, and the larger yacht sailors became tied to more comprehensive instrumentation available commercially.

In 1990 a Swiss-made pair of speed sensors - SPEEDWATCH - became available in the UK, see AYRS 108, page 24. Again, small craft and board sailors were almost totally apathetic about these, despite their excellent quality and affordable cost, to the extent that the importer, Torix Bennett, handed over the franchise to John de Heveningham, who markets the improved range. It is good to know that sales to board sailors are improving: come on, craft sailors!

Cyclists, being greater in number and keener on knowing their speed, support manufacturers who make matchbox-size devices costing around £20 upwards which tell them their speed and have available other computed numbers, for example an average, or a top speed. Athletes, having one assumes even greater purchasing power, can buy heart-beat timers/recorders which they can use to pace themselves. Real speed cyclists presumably have both. Bob Spagnoletti contributes an article on his adaptation of a cycle computer for measuring and recording boat or board speed.

The advent of the various portable computers, smaller each year, has enabled first the professional, sponsored, yacht sailors (America's Cup, WRTW etc) to use these machines aboard in conjunction with sensors for assessing performance, and in conjunction with Decca or Sat-Nav Global Positioning Systems for navigation. While a lap-top computer might be a bit difficult for a board sailor to handle, his day will come when it is wrist-watch size. Today an affordable (£200) lap-top is available which can be used in say a 20ft and larger cruiser, although the prices of sensors are still generally more, and GPS receivers are at cheapest around £400.

For smaller and wetter craft, Joddy Chapman's recording instrument affords a means of determining the performance of a 16ft hydrofoil catamaran, the analysis being performed ashore afterwards. The same principle has been around for some time in professional circles, using rather heavier equipment, as reported by John Walker in his letter about the performance of BLUE NOVA, and the characteristics of TACSTAR, its use by the racing fraternity, and its potential pitfalls. For an idea of the size of the professional gear, look at any YACHTING MONTHLY report by James Jermain on a new yacht. Does the black box also house his sandwiches ?

Bob Downhill's resurrection of Weymouth Speed Week has provided a speed measuring facility particularly for boards and craft without meters. A technical problem has been to record wind speed on the course. It is hoped that this has now been achieved and that each run at Weymouth 1995 will have a wind speed tied to it, for one end of the course or the other. Cost prohibits the use of TV, on the other hand use of infra-red or laser sensors to detect the passage of a competitor should give accuracy improved over the voice method, though there will still be the limitation due to overlapping. Bob's article recounts the recent history of measurement at Weymouth and makes some mention of his plans.

There being no end to the ingenuity of keen competitors who will stretch rules, Graeme Ward and Bruce Cartwright describe a system - again using electronics - to determine the stiffness of a sailboard, in order to bowl out the 'works special' which makes out it is a production board when it is not. As so often in sailing, is it an engineering or an athletic contest ?

Instrumented Performance Measurement and Assessment

or How well are we doing?

by G.C.& E.J.C.Chapman

Aims

Our aims in developing instrumentation for small sailing craft, apart from the interest of using our combined knowledge, are :-

* to assess the value of changes as they are made; have we made an improvement?
* to assist prediction of any benefit from a proposed modification.
* to enable comparisons with other craft once they have similar instrumentation.

The Sailing Environment

Wind Gradient

For a very comprehensive treatment of wind as it affects the sailor Frank Bethwaite's book (Ref 1) is hard to beat. He has experienced and measured winds around the world at locations used by small boat sailors in Olympic and other championships, and particularly in Sydney Harbour, and with his aircraft pilot experience has a three-dimensional feel for the atmosphere.

Much of what he says about the variable nature of wind we have confirmed for ourselves. There is no such thing as a "steady wind" such as one might imagine getting in a wind tunnel - except below about 5 knots (measured at 20ft above the water). Fig 1 derived in part from his book illustrates the nature of the gradient or variation in wind speed with height. At low wind speeds where the lines are nearly straight the flow is laminar;the air at each level flows steadily at its own level and there is no mixing. Above about 5 or 6 knots (at about 20 ft) the air starts to become turbulent; put crudely it trips over irregularities at ground level and indeed over itself, and the rougher the surface and the stronger the wind the greater the degree of turbulence. Friction from the irregularities at the surface causes more slowing down near the surface, but it is interesting to note that the mathematical nature of the curve of wind speed with height remains substantially the same as wind speed rises. Bethwaite's curves for turbulent wind approximate fairly closely to the proportions adopted by the Royal Aircraft Establishment and given as an example in Dr Hassan's lectures (Ref 2) as applying at Rugby - presumably based on measurements made on one of the masts of Rugby Radio? Those curves are consistent with the ground being covered with thick grass. Applying the factor appropriate to sea mid-way between 'calm open sea' and 'Off-sea wind in coastal areas' produces the curves in Figure 1. This suggests that the true wind at CALLIOPE's sail centre of effort level is 1.13 times that at the anemometer which is 1m. off the surface; at the masthead the true wind will be 1.32 times that at the meter.

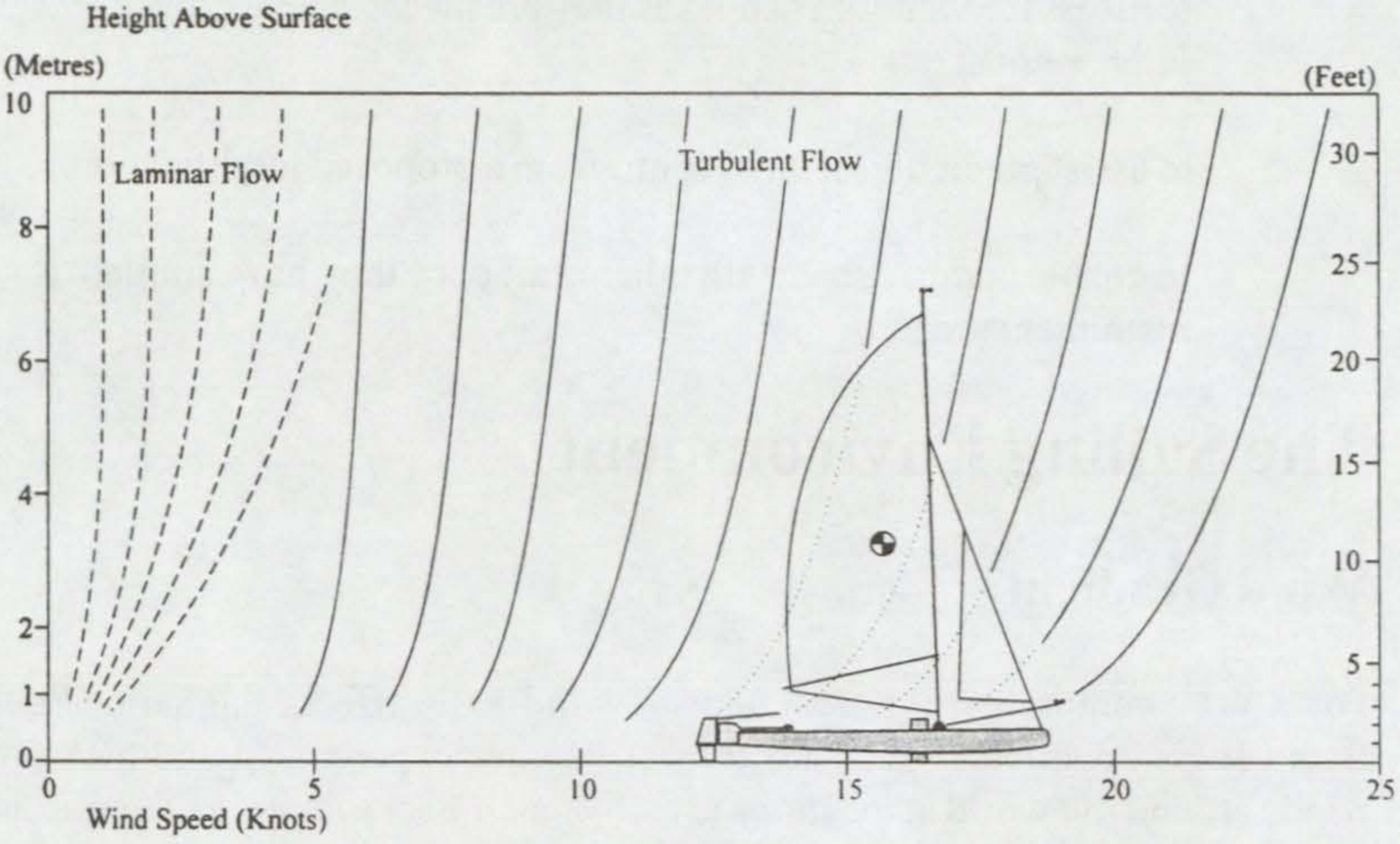

Figure 1. Wind Gradients Over the Sea

$$V_h = V_{10}\left({}^{h}/_{10}\right)^{0.0985}$$

where V_{10} is wind speed at 10m and h is height in metres - for turbulent flow.

It must be stressed that these apparently detailed differences are only long term averages, where 'long' is measured in minutes. From second to second and to some extent minute to minute there is turbulence dependant on the history of the wind's recent passage over the earth's or sea's surface. Our experience is that the speed gradient varies from day to day and indeed throughout the day. In 1994 it seemed to be more pronounced later in the season, though this may be more a matter of observation than fact. Our resolution is to try to observe and record the masthead and jib-stick meters' readings when stopped. Note that all this applies to the true wind. The apparent wind having boat speed as a component varies differently and suffers less from the gradient effect,i.e.there is less difference between speeds at particular heights.

At heights up to around 2,000m. and more the Coriolis effect turns the wind from its expected direction of movement at right angles to the isobars to the right in the Northern hemisphere, to travel almost parallel to the isobars. For wind at lower levels the effect of friction and turbulence is to turn the wind back towards its 'correct' direction. However at the heights we are interested in this effect is said to be negligible. Nevertheless we have heard that yacht navigators believe they have detected shear as evidenced by different performance on different tacks. This is another aspect which bears investigation.

Most small sailing craft with masts up to around 30 ft have little or no sail below say 1 m. off the water, unlike sailboards. So the variation of windspeed between the foot and the peak is not proportionately as great in winds over 6 knots as it is below 6 knots, which is why there is more need to allow twist in a sail in light winds. Bethwaite shows by the use of streamers on a vertical stay (his Fig.3) that in an 8 knot breeze there is negligible gradient and negligible twist when boat speed is 4 knots. Our graph of gradient, (which has a lower index of gradient than his), shows that at higher wind speeds than 8 knots there is more difference in wind speed between heights than there is below 8 knots. We believe that twist is necessary in a sail at all times but the amount will vary continuously with time. Which is a reason for sails to be tolerant of variations of angle of attack.

Because of gradient, one problem is to know at which height to specify (and try to measure) the wind speed in order to provide fair comparisons between craft. Probably the height of the centre of effort, alternatively some standard height say 4m. (13.12 ft) which is near the CE for many craft.

Putting the wind speed and direction sensors at a standard height has problems compared with sticking them on the end of the jib stick, which is where ours have perforce been.

Because boat speed (V_S) contributes with true wind speed (V_T) to give apparent wind speed (V_A), V_A does not follow the same gradient law as V_T. Also β_A (wind angle relative to boat's centre-line) will vary, indicating the amount of twist. The following Table shows typical figures for three courses. Here β is the total wind angle between the apparent wind and the boat's direction of movement: $\beta = (\beta_A + \lambda)$, λ (lambda) being the leeway angle.

			Close Hauled, not flying			Broad Reach			Downwind		
			(V_S=7, γ=57°)			(V_S=16, γ=90°)			(V_S=20.3, γ=116°)		
Ht(m)	**V_T**	**%**	**β°**	**V_A**	**%**	**β°**	**V_A**	**%**	**β°**	**V_A**	**%**
1	14	100	38	18.9	100	41	21.4	100	41.5	18.9	100
3.3	15.8	113	40	20.7	109.5	45	22.6	106	46.5	19.6	103
7	18.6	132.5	41.5	23.2	123	48	24.2	113	54	20.6	109
Twist, 1 to 7m			3.5°			7°			12.5°		

γ stands for gamma, the angle off the true wind in degrees.
% is that for the wind speed in the preceding column.

In the table above, the 1m height is that of our anemometer from the water when flying; 3.3m is the height of the Centre of Effort (CE), and 7m the masthead. Note how β varies with height and between the different points of sailing; the sail needs more twist if it is to have a uniform angle of attack all the way up, as you move away from close-hauled. Conversely, the variation in V_A as felt by the sail reduces as you bear away, and sail faster.

Many yachts have their wind sensors at the masthead. The table shows how the readings they give will have wind speeds greater than those at CE height and β_A readings more than the average for the sails. Additionally there may well be effects due to the nearby presence of the mainsail unless the sensors are mounted well forward on a stalk. Many yachts may actually point higher than they believe; and do they know what their leeway angles are? For slower boats, the twist is less but the increase in apparent wind speed with height is more, particularly downwind.

Wind Speed Variation

We have found that wind speed can vary by up to five knots from second to second, as recorded by two types of anemometer, equally at times speed is steady (within a knot or so) for a few seconds. See Figure 2. Bethwaite describes the longer term variations in speed, overall there seems globally to be a fairly regular variation with a periodicity of around one minute, which we will refer to later.

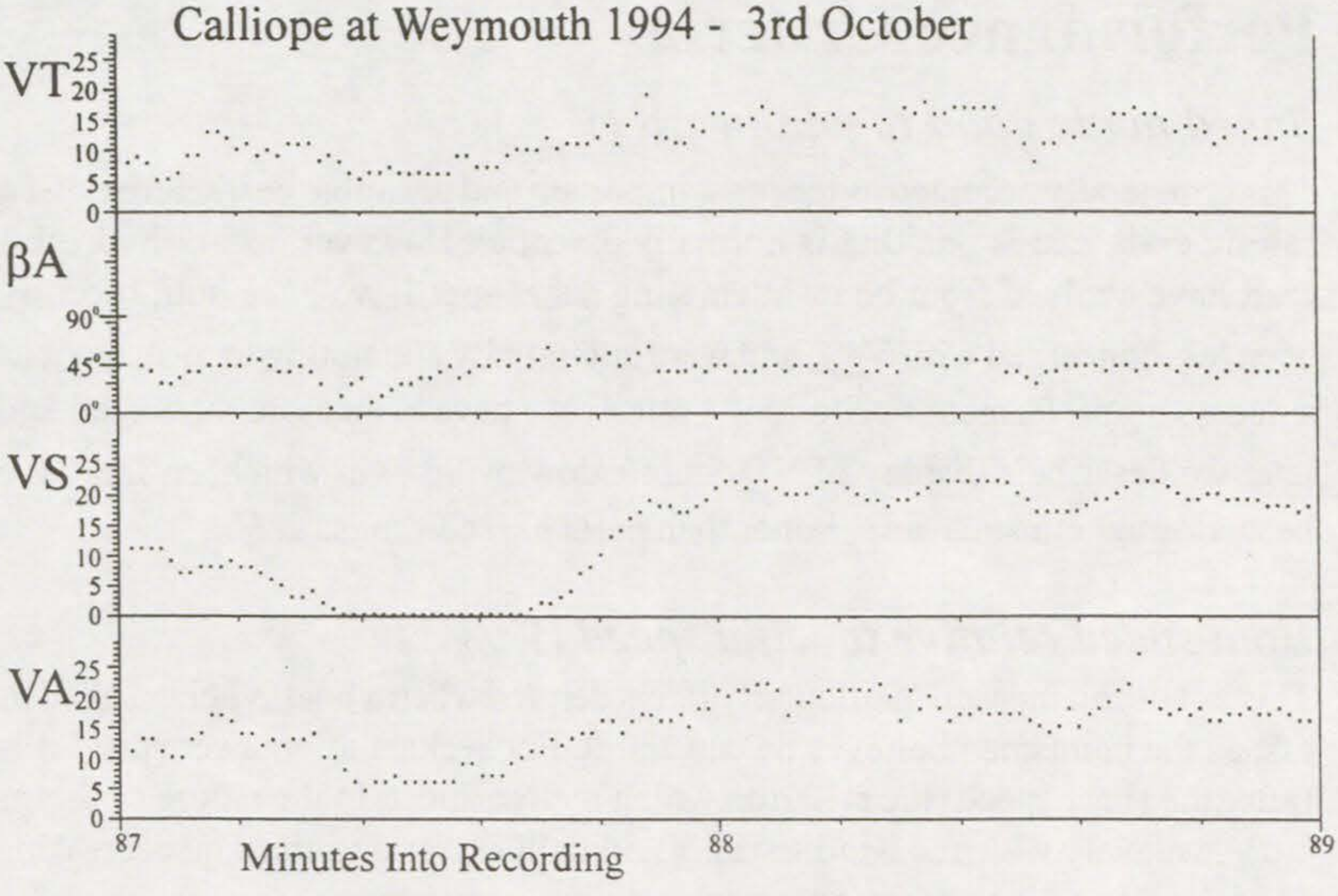

Figure 2. **Example of timewise plot**

Note that on this and some other figures unconventional labels have been used. These are the labels which are used by the computer analysis program. The explanations given in Figure 8 apply also to Figures 2, 3, 4, 5, and 7.

Wind Direction Variation

Similar second-to-second variations apply also to wind direction. At times the wind vane oscillates rapidly and then for a second or two or longer holds relatively steady. We believe this is a function of the wind rather than a natural oscillation frequency of the vane itself. Later we will describe our way of averaging records to try to produce figures which are more meaningful than are realised by a quick glance at a dial.

On top of the short term direction variations there may be longer term variations. The helmsman can and does accommodate these except when they catch him unawares.

Waves

This article deals with conditions inshore where, for CALLIOPE, at the most the waves merely slap the keel occasionally.

Performance Criteria

Speed made good to windward (V_{mg}).

This is generally accepted as the most important and desirable characteristic of a sailing craft, and is one that is normally essential. However, as our hydrofoil craft have evolved from boats attempting sheer speed, we have until recently been less concerned with V_{mg}, and were not initially attempting to measure it as a necessary performance criterion. Latterly we have been more interested and later we describe a display of V_{mg} and its downwind twin which, so far, have been aids to helmsmanship, rather than parts of recordings.

Boat speed relative to wind speed (V_S/V_T).

This is a useful measure particularly if it is derived when a boat is being sailed as fast as the helmsman believes he can sail it. For seekers after sheer speed it is (after the sheer speed) the criterion which matters most. In the nature of things V_S/V_T will vary with true wind speed, V_T, initially increasing and then decreasing as heeling force increases and - maybe - as the waves increase.

Polar Diagrams.

These plot boat speed as a vector for varying values of gamma (the angle sailed off the true wind), for - ideally - a “steady” wind of so many knots. Those published need to be taken with appropriate doses of tranquiliser except where the method of compilation is spelt out; where it is not, it may be based on shaky data and/or compilation method.

Boat Speed itself (V_S).

As mentioned above, for the speed freak this is what matters. Even so, caution is needed. Seeing a meter ‘touch’ some (high) speed is one thing, but what is the actual average over 500 m? Over 3,000 miles of ocean? Over 24 hours? We were surprised at first when our speed meter and records showed speed varying by two knots between one second and the next but realised, and confirmed after looking at the momentum and drive figures, that with a lightweight boat this is quite possible, particularly with the wind speed variations mentioned above. Unlike a motor car or an aircraft which is propelled by an engine running at constant power, any sailing boat is driven by a constantly varying power source and with a lightweight craft, or with large waves which allow ‘downhill’ travel - or both - the instantaneous speed can be knots more than the average.

Our Instrumentation

What follows immediately is a general description which attempts to avoid too much technical detail. That is in a separate section later.

Our first water speed meter was a Smith's pitot-type meter which gave many years service using pitot tubes built into rudders. The meter itself is a pressure gauge, and as far as we could see gave a fairly accurate reading. There was some damping overall but even so the needle bounced about quite a lot. Of about the same vintage was another Smith's instrument, an anemometer with the three-cup rotor driving a small AC generator. The output voltage is rectified to drive a simple meter with a non-linear scale. This has been replaced by a larger (yacht size) Smith's meter which has the same cups unit at the masthead but a larger display which incorporates damping. A gust pushes the needle up quickly, it takes longer to fall back, in an attempt to present a more readily readable 'average'. All these instruments are self-powered.

For the new generation of instrumentation starting in 1993 we decided to make use of some commercially available devices, adapting them as appropriate for our needs. For speeds the starting point has been the SPEEDWATCH range, described in Ref 3 in an early version. This is the sailing equivalent of the matchbox-size speed calculators sold for bicycles or for displaying and recording your heart rate if you are an athlete - or both. The essentials are water and wind speed sensors - a small impeller and a tiny windmill - which have integral magnets. As these are rotated a coil picks up the varying magnetic field and the electronics converts this into a display of knots and decimal knots. Both for water and wind the device counts for about 3/4 of a second, then does the computation, and then shows the answer on a digital display where it remains for a second until renewed.

The other commercial range of instruments which are suited to small craft (and small pockets) are those of AUTONNIC. (Ref 4) These are mostly intended for rather larger craft than are SPEEDWATCH, but are equally applicable on small multihulls, at least. We also use their anemometer cup unit in conjunction with our own displays and recording equipment, It too rotates a magnet which actuates a reed relay; with the appropriate counting it works as well as the SPEEDWATCH little windmill, and is omnidirectional. AUTONNIC sell a range of water speed sensors for various methods of attachment or towing which again depend on a rotating impeller's magnet to actuate a reed relay, as well as wind direction instruments.

AUTONNIC sell both digital and analogue meters to go with their sensors, and it is a matter of taste which you choose, and a matter of practice to get used to either. Digital displays tend to have the capability to read to a higher figure, and are easier to read at a distance. AUTONNIC's simpler instruments have self contained batteries which are claimed to last a season.

On CALLIOPE we have buried a small coil of 44 swg wire wound on a sewing machine bobbin in the rudder, the SPEEDWATCH impeller is carried on a 2mm wire arm about an inch clear, and is sufficiently close that speeds down to 1 knot and less can be registered.

In order to save cost, weight and effort our system uses only 32 levels (5 bits) in each of the three primary quantities, V_A (Apparent wind speed), V_S (Boat speed) and β_A (Apparent wind angle). So for CALLIOPE we can read and record speeds up to 31 knots but only in 1 knot steps; and each knot registered means 'a speed between the whole number of knots shown and the next knot up'. For wind angle the device works in 5.625 degree steps, the zero step being 2.8125 degrees wide either side of right ahead. We can see which tack we are on, we don't need to be told. In a monohull application boat speed could be recorded in say quarter knots to 7.5 and wind angle to a finer resolution over the close hauled arc of interest. The step to 8 bit working is not so difficult and will give 256 levels for each parameter.

The β_A device is thus a small wind vane incorporating the wind speed windmill. Below this is the speed coil, and below that in a GRP box is the transparent disc with blacked out segments interrupting the infra-red emissions from five emitters in order to provide the appropriate signals to five IR receptors. So apart from the bearings the vane is virtually friction free. Commercial β_A meters appear to provide greater resolution - they transmit to nearer a degree AND tell you which tack you are on - but they come more costly and are more difficult to repair if they fall in the water.

"Apparent wind direction" is what it says. It is not the strict β (beta) which is the angle between the apparent wind and the direction the boat is moving, rather it is $(\beta - \lambda)$ where λ is the leeway angle. Measuring λ is not easy. Fortunately for hydrofoil supported craft it is easy to calculate the leeway angle and in performing an analysis and subsequent polar predictions it can be allowed for accurately. With displacement craft it is a matter of estimation (guesswork?), or careful navigational analysis.

So we have, from the electronics, 15 bits total of output from the three sensors which makes recording and processing relatively easy.

Displays.

In the outfit we use on CALLIOPE we already have a SPEEDWATCH digital display of boat speed and a Smith's analogue (masthead) display of apparent wind speed. In a home-equipped box besides the other electronics we have a two digit display which can be switched to show one of the following:-

V_A - Apparent wind speed - knots by single knots zero to 31
V_S - Boat Speed - knots by single knots to 31
V_T - True Wind Speed - knots by single knots to 31
V_{mg} - Boat Speed made good to windward - knots and decimal knots (you have to remember to insert your own decimal point), (with a minus sign if downwind; see below)

Alternatively to V_{mg} downwind:-

Gamma - shown as degrees beyond 90, with a minus sign in front.

Of the above, V_A and V_S are being received from the sensors and can be shown directly. The other parameters depend on the electronic equivalent of a 'look-up table' contained in an EPROM (Erasable Read-Only Memory). There is no microprocessor in this unit.

We differ in our use of these, and it depends on the point of sailing and what one is trying to do which one chooses to have shown.

The value of the Gamma readout is when trying to make best speed downwind at around 120 degrees (indicated) and more off the wind, to avoid 'falling off the edge' and slowing down into the dead-down-wind arc. Obviously we already have V_S and masthead V_A visible, but these are available as a cross check, normally one of the others is shown on our box.

Recording

The box described above with a display also contains a battery-backed RAM card which will store the raw data from the sensors. 2 hours 15 minutes recording time is available. The card has to be removed from the box for the data to be downloaded into a PC for subsequent analysis.

Limitations

Resolution. As stated above, our instruments indicate and record to the nearest knot below, or within a 5.625 degree arc. Later we describe how we use averages over a period of around a half to one minute and we believe this produces adequate resolution for our purposes.

Accuracy. For speeds this depends on the timing accuracy embodied in the electronics, which can be 'tweaked'. Its timekeeping is within about 1%, good enough for us. In any case our figures for speeds all err on the low side and it is arguable that we should add a half knot to any averaged figure.

Wind Measurements. We have discussed above the gradient which has the effect of reducing the wind speed measured compared with that at Centre of Effort height. In analysis this can be allowed for. If the wind vane is too close to the jib it will sense the wind deflected forward around the jib, giving an over-reading. Location of the wind sensors is a matter of compromise. At the masthead itself is also probably less than totally satisfactory, but carried forward on a spur will probably give truer data.

Records and Analysis

More recently another smaller box, without a display but which does not have to be taken apart for the downloading procedure, can record three parameters for three hours, or one for nine. Based on an 8031 microcontroller, this unit has the potential for greater resolution (with the appropriate sensors). Details are at the end of this article.

Once downloaded into a computer the data can be presented in a variety of ways.

Timewise Plot. This plots V_A, V_S and β_A together with V_T calculated for each second's values. There is a choice of horizontal scales from 120 down to 2 minutes so that from an overview one can in effect zoom in to an area of interest. Figure 2 is an example.

"Best Speed" Plots. (Figure 3) Still with a timewise display is a routine which will find the fastest 500m or 200m run and produce the printout shown. For those interested in speed sailing this is invaluable because one can sail across literally hundreds of consecutive and overlapping 500m courses and pick the best without the hassle and expense of transits and timekeepers and the rest. The program also prints out the average V_A and β_A and from these the V_T and gamma (γ) which are a first approximation as to what was actually happening during the run; also V_S/V_T for the run.

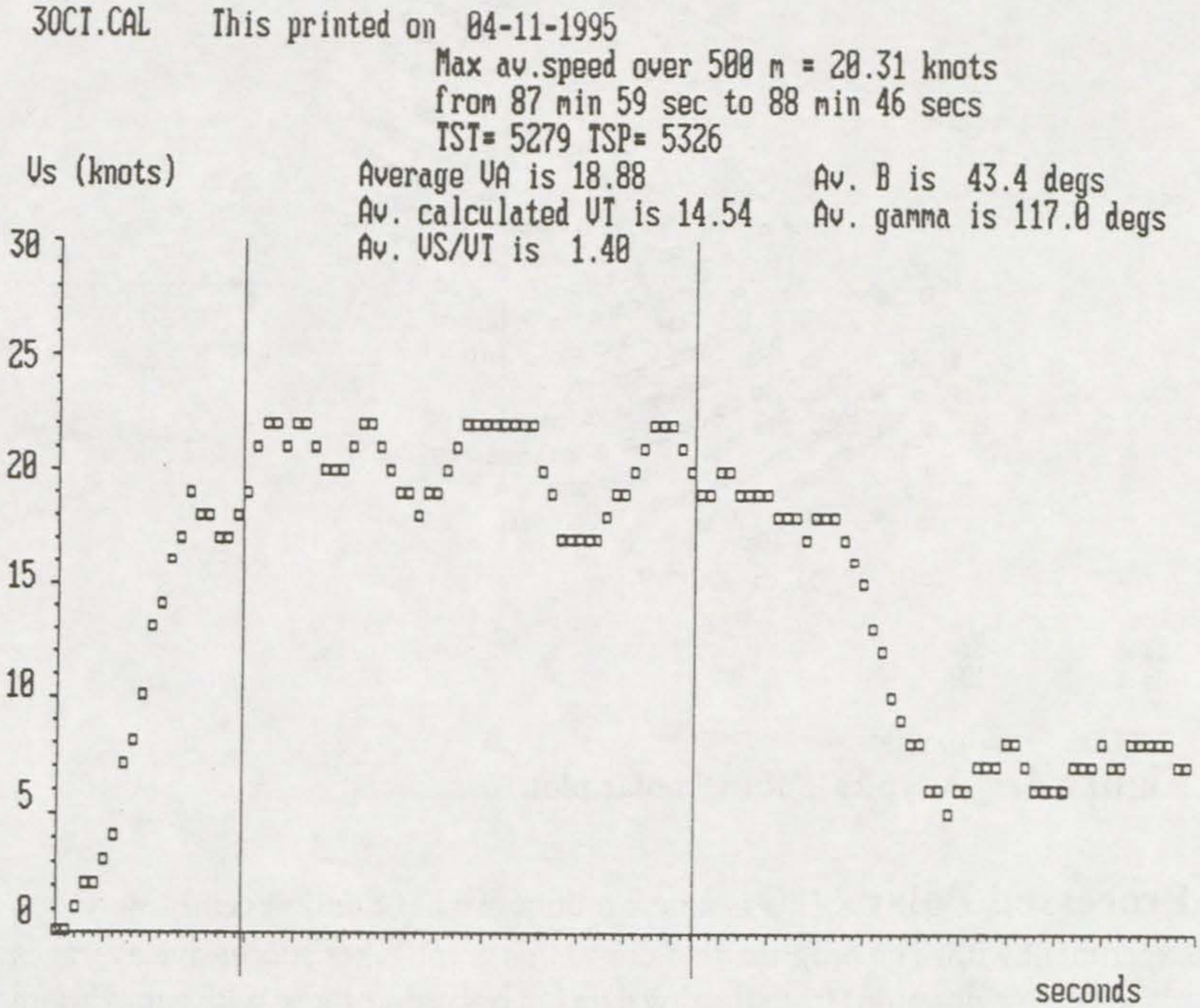

Figure 3. **A typical "Best Speed" plot.**

At the speeds we sail a 500m. run takes around a minute. During this time the boat will probably experience the almost universal periodic variation - gust to lull and back - which has a periodicity of about one minute. This periodicity is normally visible on our plots of V_T. It is something we all have to put up with; and if you are in the 50 knot class then you must choose your gust - or lull - with care.

Raw Polar Plot. The program can plot for every second in a chosen period - Figure 4 is a 20 minute period - a point representing the speed (as a vector from the centre) and the direction off the true wind, γ (gamma), and this example includes tacking and stopping. We can sail directly to windward! But only very briefly while tacking. One could draw a line around the outside and say ‘this is the envelope inside which you can expect the boat to perform’ but it would not be an accurate depiction of what is possible in steady sailing.

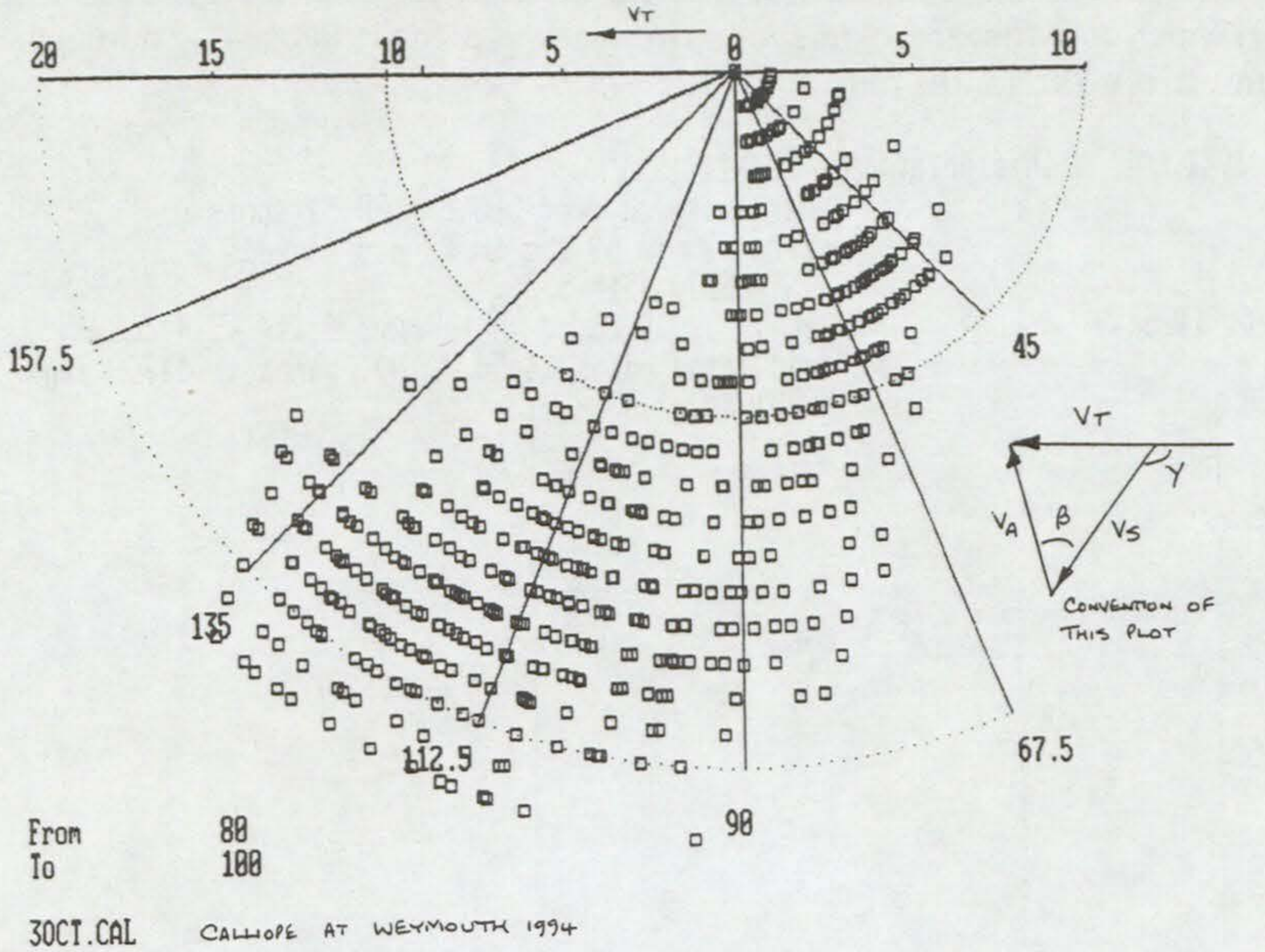

Figure 4. **A typical "Raw" polar plot.**

Processed Polar. This is a new routine we have only recently started to experiment with. The program that draws this graph takes successive averages (of selectable duration) from the raw data but only plots those with a maximum boat speed for each 10 degree arc of gamma from 45 degrees to 155 degrees to produce the typical curve shown in Figure 5. An additional "filter" ignores points where the calculated true wind speed is greater than a given value, to eliminate rogue points. In the example here, Figure 5, the averaging interval is 10 seconds and points where V_T is more than 14 knots are ignored.

Tests show that 10 seconds is a realistic interval, since the curve for 14 knots of true wind (at 1m) cuts the point achieved over the 500m course at an average of 20.3 knots V_S. Put the other way, if the boat can achieve a speed over ten seconds, then with concentrated helmsmanship it should do the same over a longer period provided the wind holds.

It has been interesting to run this routine with data from outings on days of similar weather from our two years worth of records to see the improvement in performance and compare with our mathematical models.

It has also been possible to superimpose the points for various true wind speeds recorded during last year's Speed Week and compile a cumulative polar for the week. This has formed the basis of 'facts' for the prediction program described next.

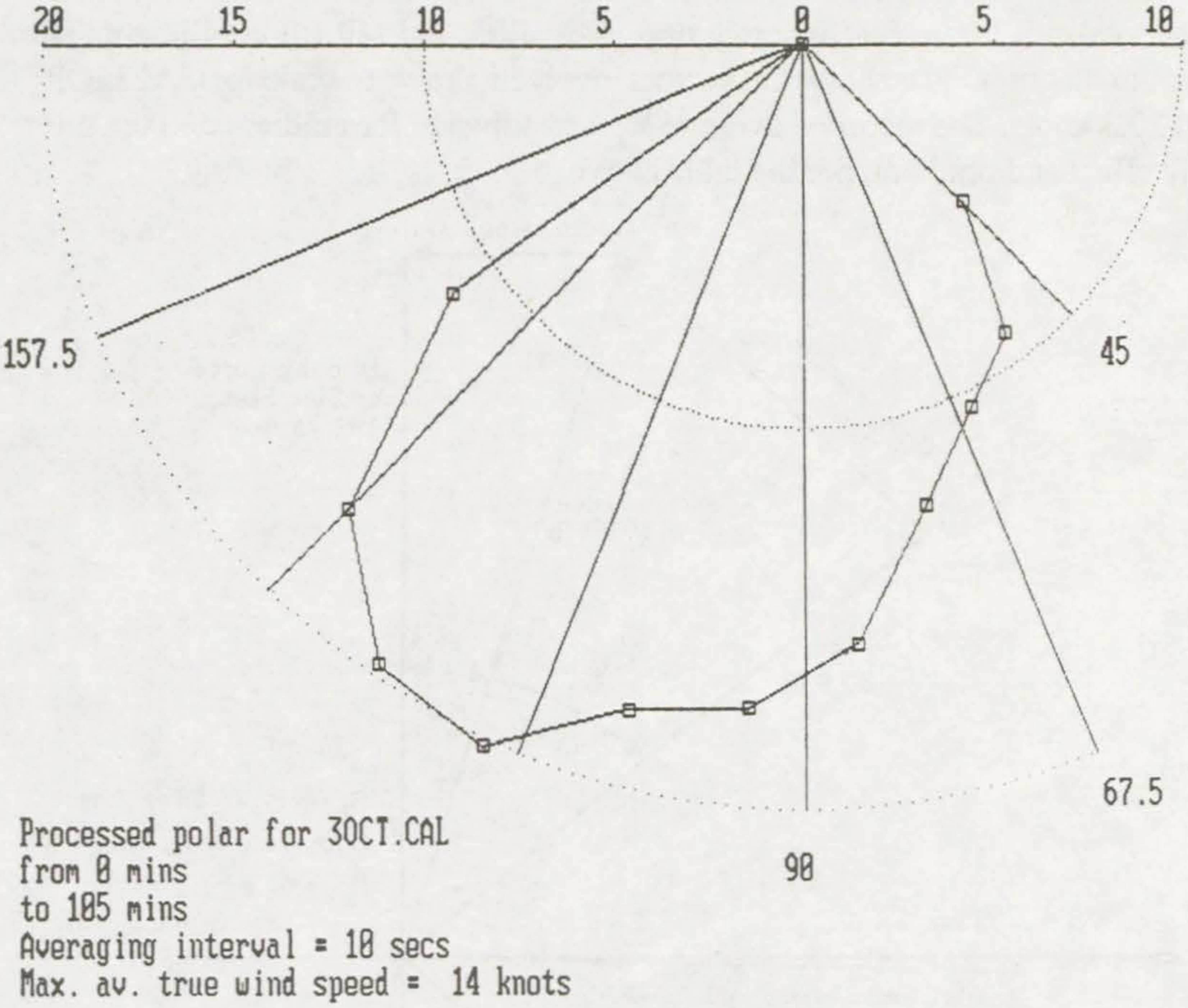

Figure 5. **Processed polar plot for True Winds 14 knots and below.**

Polar Prediction

The designer of a craft like CALLIOPE or Dr Sam Bradfield's HS21T (or new EIFO) trimaran foiler is fortunate, compared with the designer of a displacement boat, and more so compared with the monohull designer. This is because a craft flying on horizontal foils with vertical struts can have its drag calculated using well documented data, and as it remains substantially upright the rig can be considered to be vertical.

If one assumes the rudder foil and rudder to be unloaded, and postulates a distribution of weight between the two main foils, it is then simple to calculate the drag for any speed, also the heeling or side force, and hence the leeway angle. This can then be added to a known value of $(\beta - \lambda)$ (apparent wind angle) to give the full value of β.

If then, one has data from a recorded run which was made with a known distribution of load - and the obvious one is where the weather foil is seen and believed to be at 'neutral', i.e. unloaded, - it is possible to calculate in succession the total sail force, aerodynamic drag, sail 'lift', and sail lift coefficient. The vector diagram Fig 6 shows the vectors involved, drawn to scale for CALLIOPE at 20.3 knots. The recorded average V_A was adjusted for gradient and the β for jib effect and gradient, per the table above.

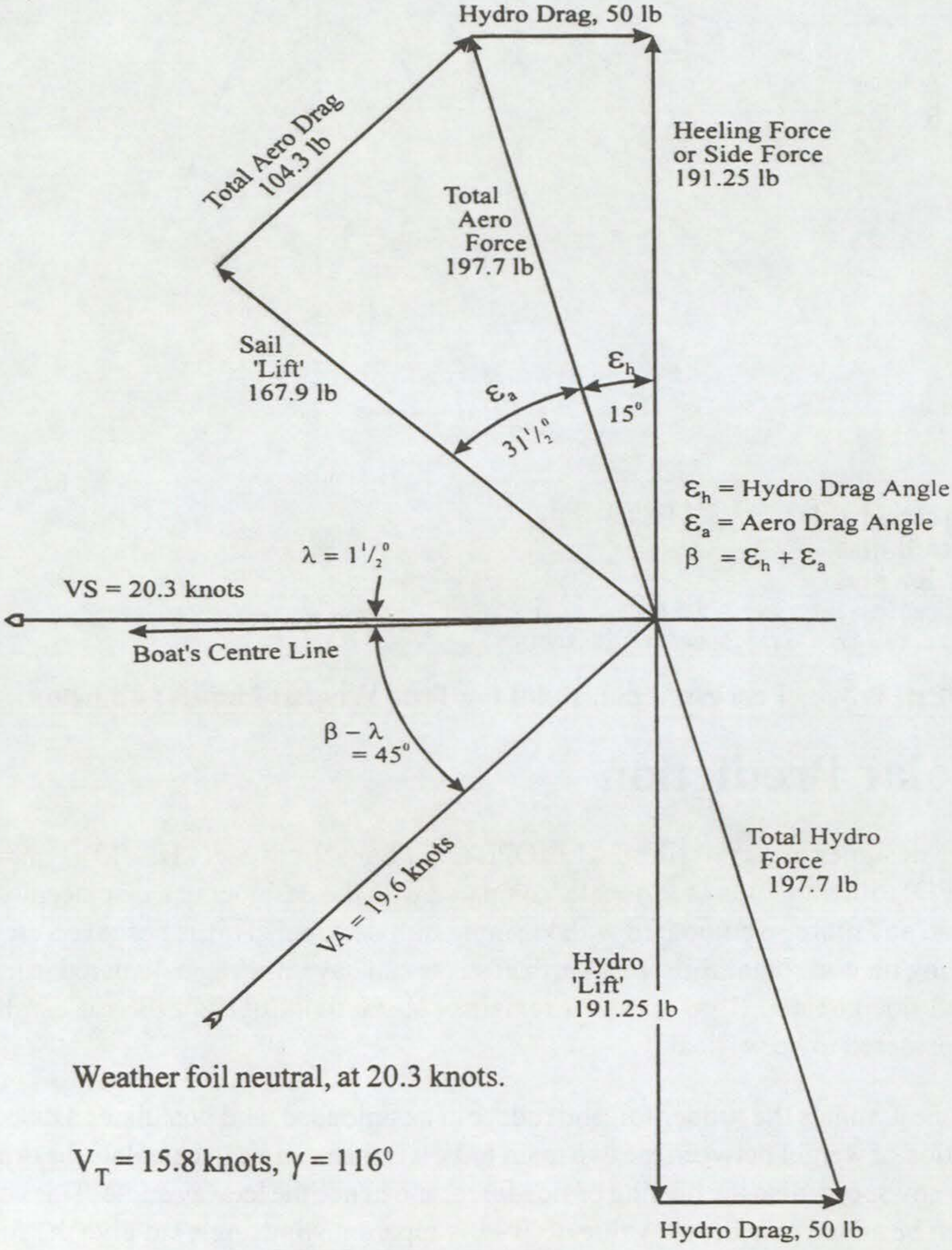

Figure 6. **Calliope Sailing Forces**

At first sight the aerodynamic drag of 104 lb seems large. Comparison of the sail characteristics with those shown by Bethwaite for a wind-tunnel 'sail' with a TASAR mast suggests that for the derived lift coefficient of 1.08, the drag coefficient would be around 0.38 at an angle of attack of 22 degrees. This leads to a mainsail drag of 59 lb, so that the jib, rigging, hulls and crew account for the other 45 lb.

It also leads to the suggestion that one might calculate the total aerodynamic drag -104 lb - by considering an appropriate area and applying the apparent wind speed squared, a drag coefficient and the relevant constant. Taking as area the side-view area, boat overall length times total height times a half, yields a drag coefficient for CALLIOPE of 0.37. To the extent that, when flying, a foiler is generally relatively close hauled, it seems reasonable to calculate aero drag when flying at any wind speed on that basis.

Figure 6 shows the sailing conditions for CALLIOPE flying both hulls in a particular true wind (15.8 knots), with V_A at 19.6 knots and V_S at 20.3; in fact our 'best 500m' on the run which was timed at 19.01 knots at Weymouth on 3rd October 1994. As far as we can tell the weather foil was unloaded most of the time. Accepting that assumption, it is possible to program a computer to examine a range of cases varying β, foil loading, boat speed etc and where it finds a set of conditions where aero drag calculated from one direction matches that calculated from the other direction for a particular V_T, to plot the point on a polar diagram.

Figure 7 is the printout of predicted polar for 15.8 knots of true wind for CALLIOPE in the condition she was in on 3rd October 1994. Also plotted is the seminal point, which was for the true wind speed of 15.8 knots at 3 m, 14 knots at 1m. Square points are where the weather foil has to have negative incidence. Close to the seminal point confidence in the truth of the polar is high, it tapers away towards the ends, where in any case a different sail lift coefficient will probably apply.

You can take the parts other than the 3rd October point with as much salt as you wish! The value of this exercise ultimately should lie in its ability to assist in selecting improvements. The corresponding polars for CALLIOPE with the previous set of foils which were in use for most of the summer of 1994 show, by comparison with Fig 7, the sort of improvement in performance we experienced. Equally, applying the parameters of the new sail we have had made for 1995 suggests that there will be a further small but noticeable gain in speed off the wind, but little if any gain in V_{mg}. It also shows by the increased proportion of square points in the windward going sector that when flying to windward the weather foil will be to DIVE; something to be watched and not really desirable.

For safety one will be able to ease the vang and twist off the top of the sail. Further recording whilst on windward legs will enable comparison with the polars and some degree of validation of the accumulated data and the program.

One must remember that the prediction is for the wind and Beta at 3m, and includes leeway angle; so the curve is slewed anti-clockwise some degrees compared with the processed polar of Figure 5.

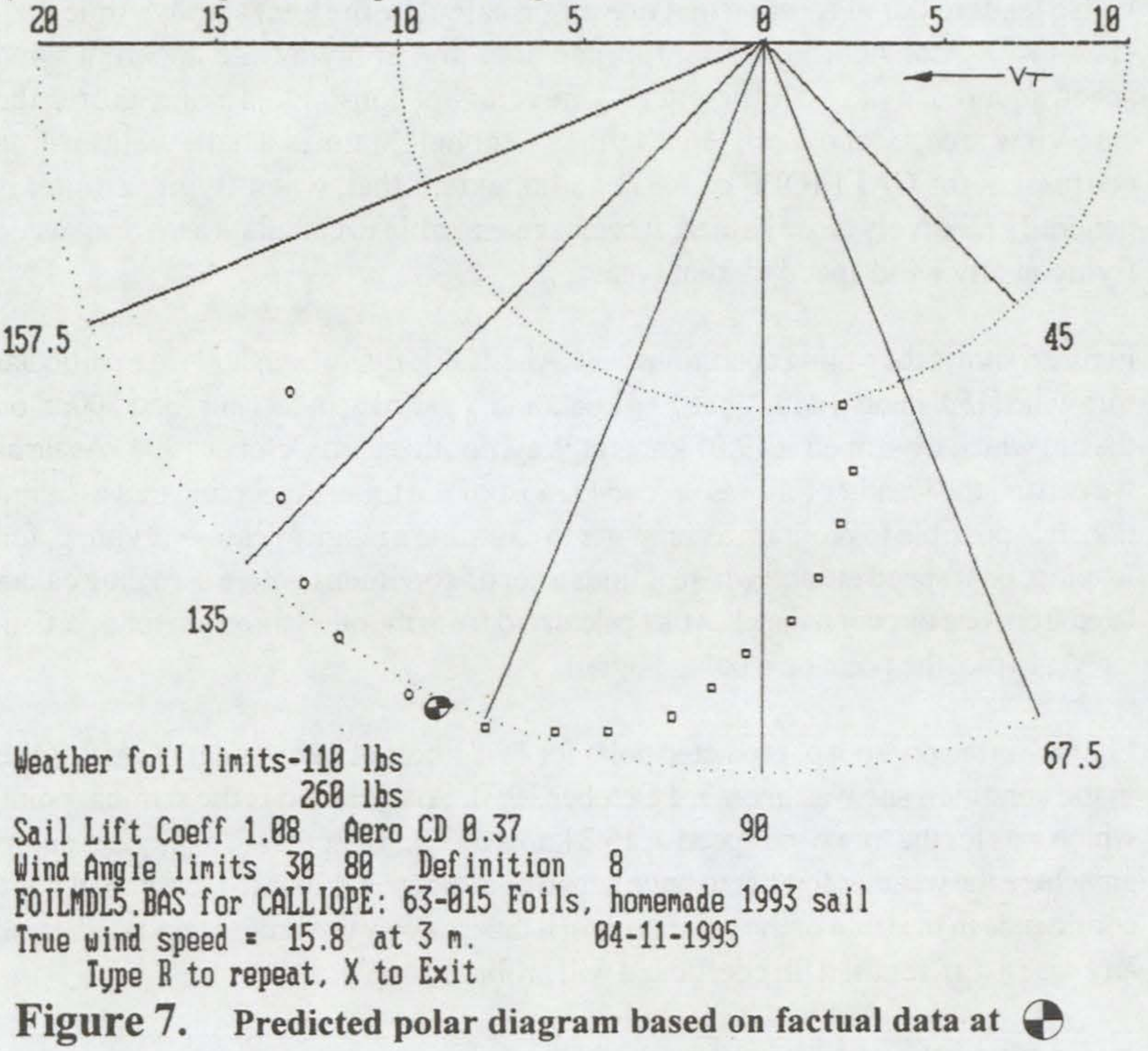

Figure 7. **Predicted polar diagram based on factual data at**

Towing tests

During Speed Week 1994 on a calm day Bob Downhill towed CALLIOPE behind his inflatable. There were two of us aboard, one to steer and one to watch the spring balance and hold the end of the tow rope. With no sail set, and foils connected, we needed additional rudder foil incidence to get the boat level and flying, and managed to work up to nearly 15 knots before a moment's inattention to the steering nearly caused a shipweck and we slipped the tow. At first we did not believe the tow rope pull of 63 lb at 15 knots. However, careful analysis of the figures taken towing in the three states, namely flying both hulls, flying one, and displacement, and applying the method described above yields useful results. From the flying both hulls figures we have the appropriate aero drag index for ahead travel without sails set, and from the other two we have an idea of the drag of a hull in the displacement mode. From all these it has been possible to construct a program for one hull flying. This suggests that for CALLIOPE one can go to windward better flying one hull than two, which again confirms our experience. This next season we hope to record performance doing just that, in order to validate the program.

Values for the various variables can be extracted and when plotted against gamma yield Figure 8. This suggests that in terms of speed, flying one hull is quicker round to a cross-over point at gamma 86 degrees at nearly 15 knots. In practice we find that 12 knots is about the maximum comfortable speed flying one hull and would probably make the change as we bear away at around gamma 80 degrees.

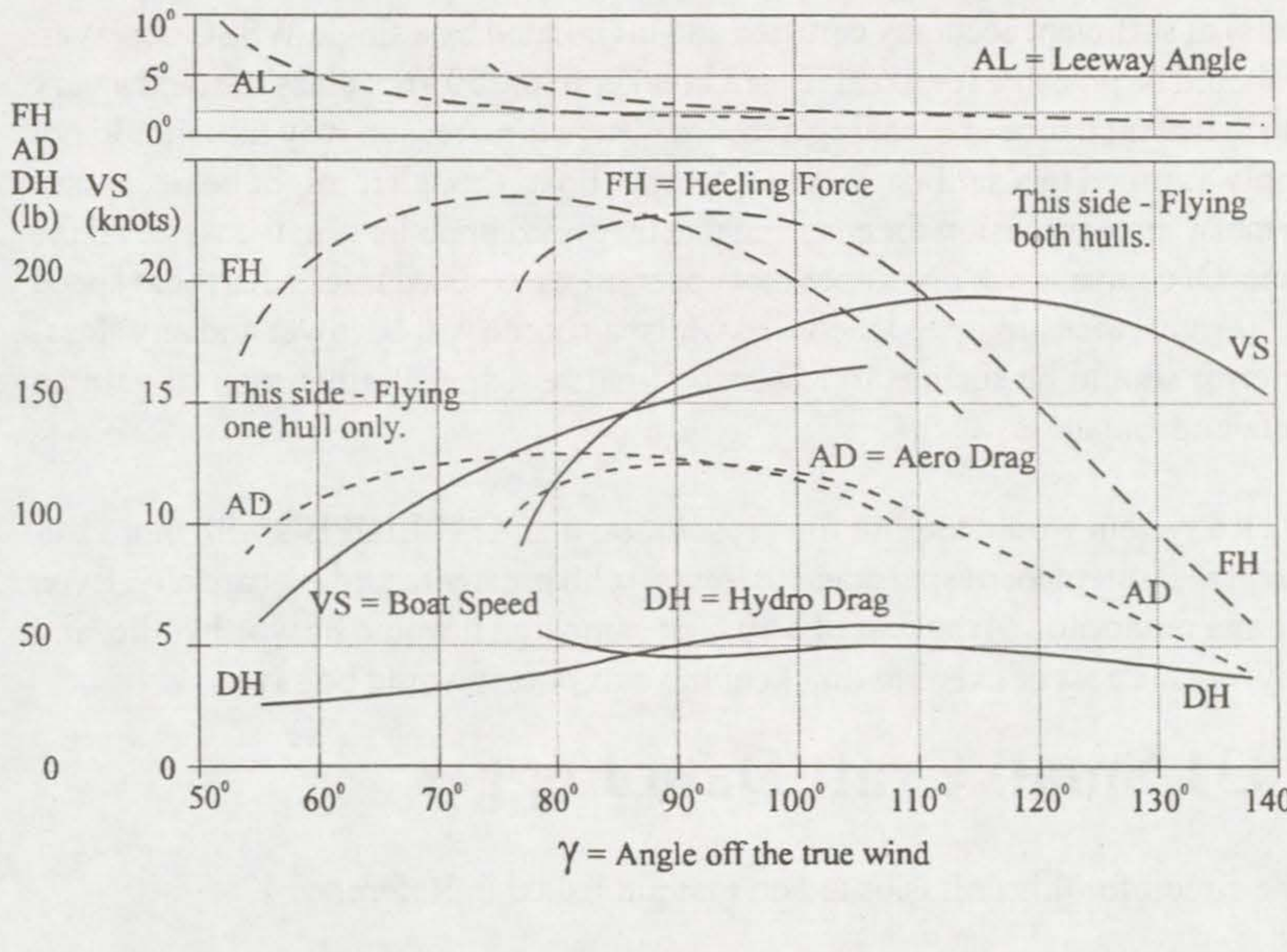

Figure 8. **Comparison of variables for flying one or two hulls.**

Sheer Speed - The Potential Use of Instrumentation

As described above, on an outing one can sail hundreds of runs over 500m. 'courses'. On a day at Weymouth one or more of these may coincide with a run timed by Bob Downhill's team. Our examination of records from 1994 shows that there is a good correlation, allowing for our figures probably being anyway half a knot low. The fact that our 500m is not necessarily the same as Bob's need not invalidate our run, and there is nothing in the WSSRC rules to specify the 500m, any more than there is to specify a particular 24 hours if the maximum distance in that time is the record you seek.

At the least our sort of instrumentation - even just recording boat speed - will give a potential speed record breaker a very good idea of whether his boat is likely to beat a record, without the expense of external timekeepers.

At the best, with recording equipment for boat speed (if not for the other parameters) of sufficient accuracy certified and invigilated by a single WSSC observer, it should be possible for a real record breaker in the 50 knot class to stand a very much better chance of breaking a record. There is no reason why this should not apply as much to a sailboard as to a 'proper boat' though it might be necessary to make some provision for ensuring that the speed impeller is in the water all the time. Of course, since one hopes that apparent wind speed is less than boat speed at 50 knots, then any speed recorded whilst airborne will be lower and any 'loss' or error should be such as to lower the final best speed rather than to gain an unfair advantage.

Such a system would require finer resolution than CALLIOPE's with more frequent measurement of speed;and therefore with greater recording capacity. Even so, as a proportion of the cost of a 50 knot campaign it would be worthwhile, and anyway the cost of existing timekeeping equipment would be saved.

8031 Small Craft Data Logger

The circuit for this unit is based on that published in Reference 5.

The 8031 is an 8051 but without an internal ROM. Two ports of the device are used to access the external EPROM and RAM, but this still leaves sufficient i/o pins for this application. The controller contains built in counters and serial data handling circuitry.

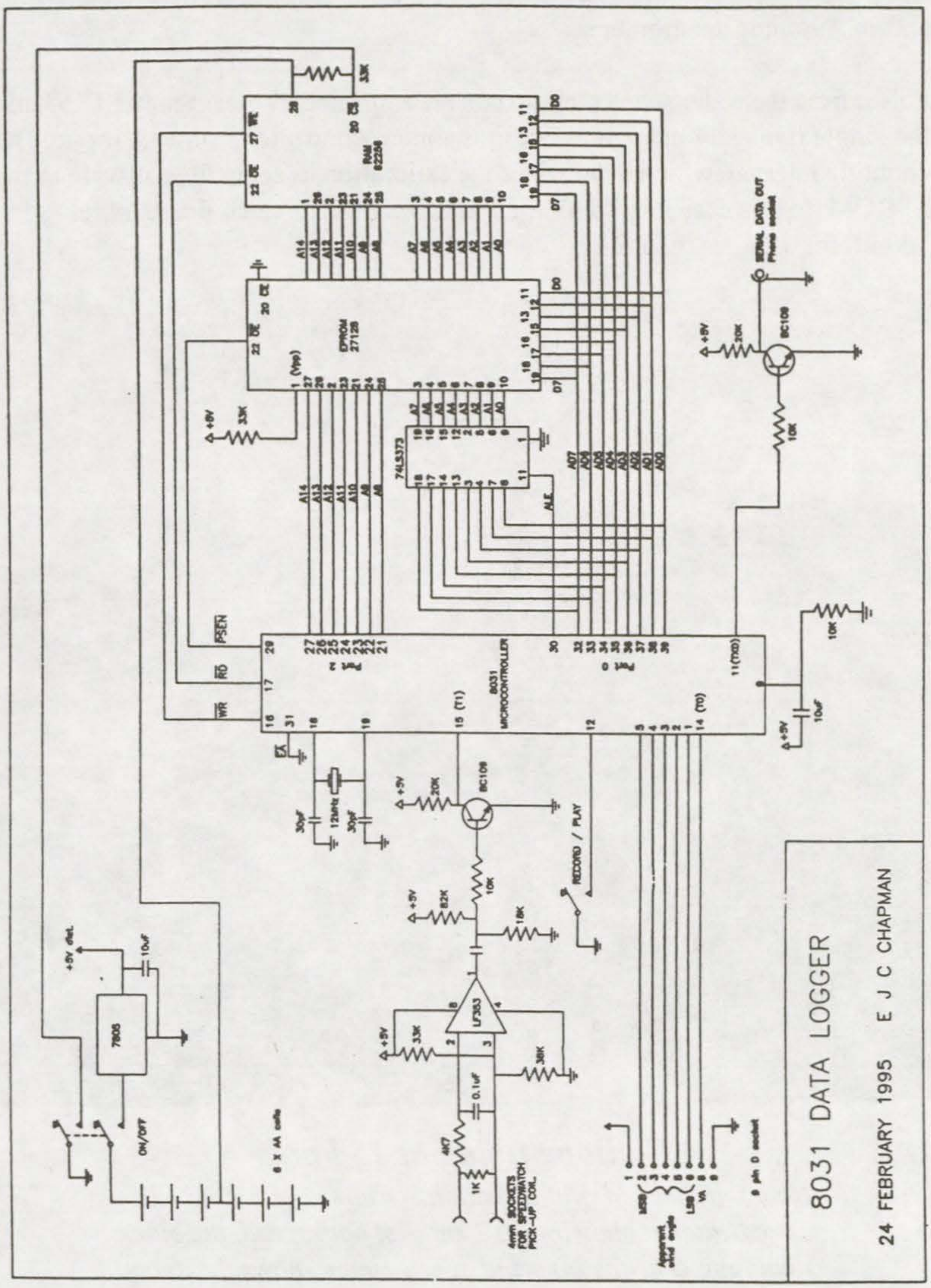

Figure 9. **Cicuit diagram for data logger.**

The circuit shown in Figure 9 is for use with a Speedwatch water speed impeller and pick-up coil, a home made 5 bit optical shaft encoder (for wind direction) and an Autonnic anemometer.

Pulses from the water speed pick-up coil are amplified by the op-amp LF353 and the single transistor stage and fed to the microcontroller's timer 1 input. The counting interval, which determines the calibration, is set in the software in the EPROM. In this case it is 76mS for 1 knot resolution but could be increased to 760mS for 0.1 knot resolution.

Calliope flying at 15 knots

Note wind speed and direction sensors on jib stick. The Speedwatch is showing 15.? knots of boat speed, the black analogue (masthead) wind speed meter shows 12 knots, and the 'Joddy Box' shows -09 knots of V_{mg} downwind.

So V_T = 10 to 11 knots and $(\beta-\lambda) = 40^0$.

The 5 bits representing the apparent wind angle go straight into pins 1 to 5 of the 8031 and are stored in the RAM at one second intervals along with the counts for boat speed and wind speed. The latter is derived from the 8031 counting contact closures from an Autonnic anemometer over 100mS. The nature of the 8031 means no de-bouncing is required.

If an Autonnic boat speed sensor were to be used then the op-amp and transistor could be omitted. If the resolution of the wind angle sensor were increased to 8 bits this could be accommodated by using pins 6, 7 and 8 in addition to 1 - 5 of the 8031. The circuit is as it is because it uses sensors from the first generation of CALLIOPE's instruments.

Wind Direction Sensor

This is a home made optical encoder. A disc encoded to the Grey code (Figure 10) is sandwiched between two printed circuit boards separated by 1/2" spacers. The wind vane is mounted on the same shaft as the disc.Infra-red LEDs on one PCB shine through (or not) the disc onto photo-transistors mounted on the opposite PCB. The output from the transistors is buffered and converted to ordinary binary code by a quad x-or package. Figure 11 shows the circuit.

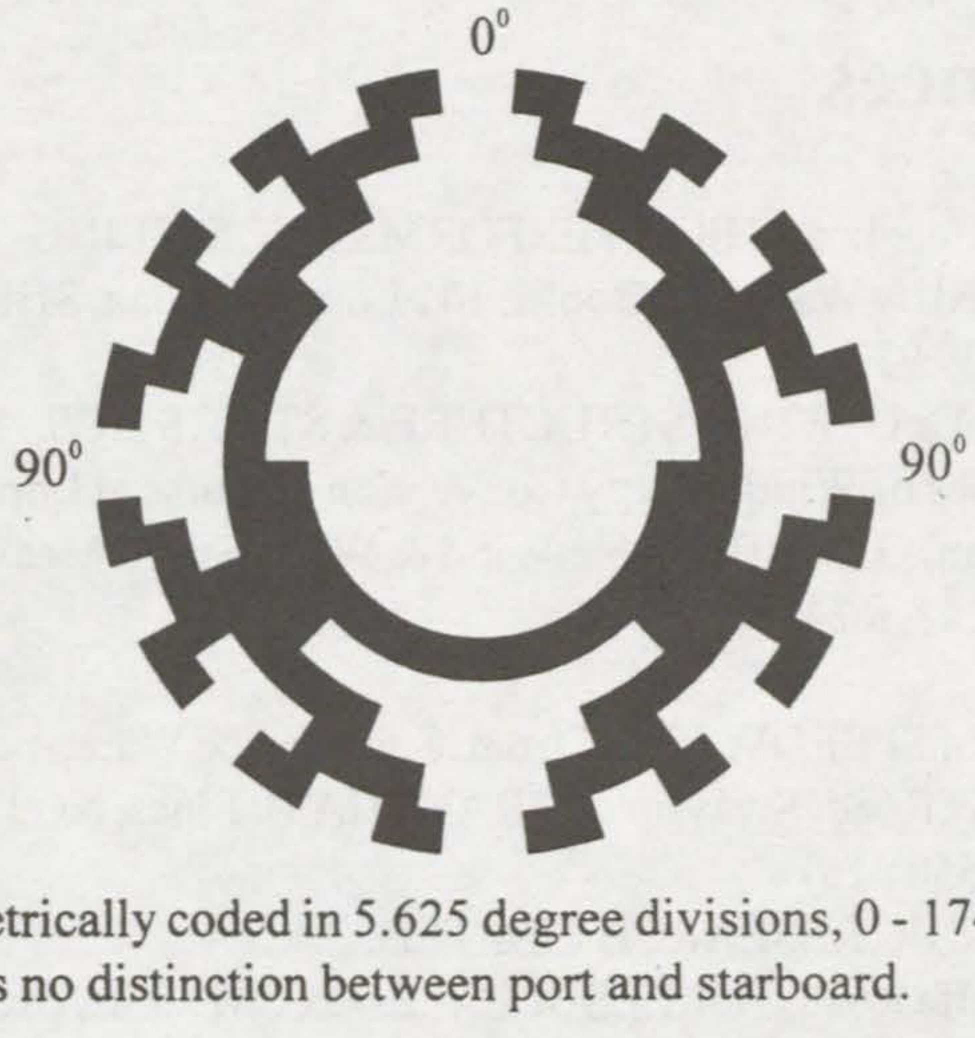

Figure 10.

Grey code disk.

The disc is symmetrically coded in 5.625 degree divisions, 0 - 174.375 degrees each side. There is no distinction between port and starboard.

These encoders were very time consuming to make so any future design would probably use a servo potentiometer and an A to D device mounted in the wind direction sensor.

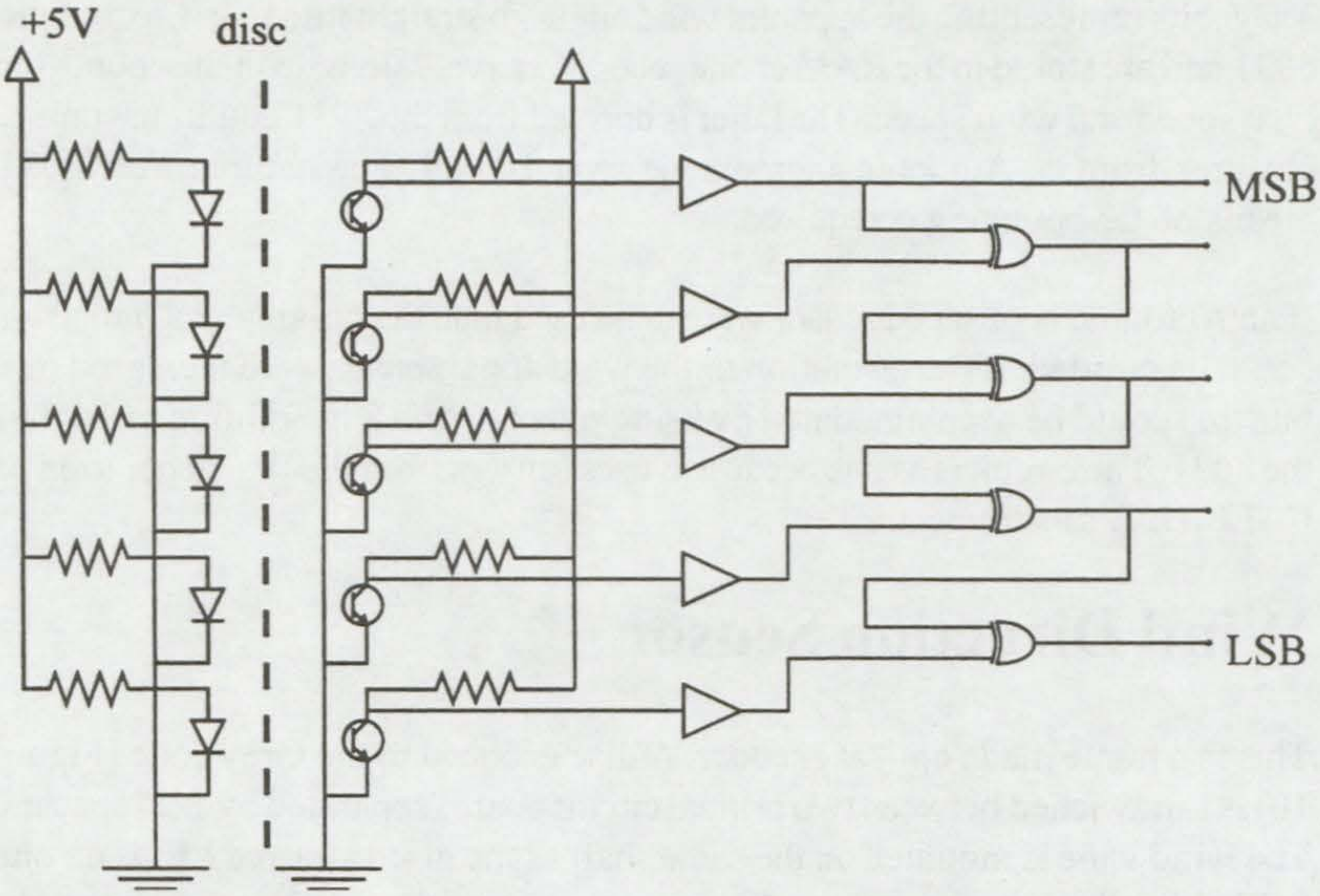

Figure 11. **Circuit diagram for optical disc anemometer.**

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4. AUTONNIC RESEARCH LIMITED, Woodrolfe Road, TOLLESBURY, Essex CM9 8SE, UK (01621 869 460, fax 868 815)
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'Calliope' - Update To End-1994

by George Chapman

This note updates the AYRS reports of AYRS 112 and 115, to the end of 1994.

Underwater Changes

For 1994 we switched to new struts and foils. To eliminate strut ventilation we adopted a Frank Bethwaite suggestion, based on his work on rudders, and made 8 inch chord struts of NACA 0012-34 section a few inches longer than the previous ones which had sharp leading edges. This laminar flow section has a rounded leading edge of radius 0.4% of chord. There is no need for fences and we have not been bothered with strut ventilation.

We decided to have the foils complete move, rather than continue with movable flaps. There is a 3" wide hub at the bottom of each strut carrying a stainless steel shaft in needle roller bearings with crank and push rod actuation from above. The stub shafts carry the foils which are secured with 6M bolts (as grubscrews) allowing rapid change of foils.

The first set of foils were of NACA 0015 section, and failed after some hours of use because we had not appreciated the magnitude of the suction force on the upper surface. The second set embodied the necessary manufacturing improvement, were slightly larger and in another laminar flow section, NACA 63_2-015.

The inboard feelers continued to serve well with less load on them due to the near-perfect balance of the foils, which dictates their plan form. We suffered some porpoising at first but reduced gain cured that. We also found that we could simplify the clutch mechanism.

Sail Changes

Again following Bethwaite we confirmed for ourselves that what he says about the TASAR mast is true, namely that the square cut trailing edge of the mast promotes attachment of the turbulated air to the sail. The nearest equivalent to the TASAR section of sufficient weight is the EUROSPARS' Z170, so we made a new mast of this section and modified the existing sail to suit and to achieve the desired camber. We also lowered the forward end of the wishboom, and arranged the boom and vang attachments to control the rotation of the mast so that it faces directly into the apparent wind. Multiple tell-tales showed the improved attachment of the air, and are essential to enable best operation of the sail.

Performance

During the 1994 summer season our main criterion of performance was the ratio of boat speed V_S to true wind speed V_T, measured with the instrumentation which is described in another article. This showed steady improvement during the summer due to both technical changes and improved helmsmen skills. The 63_2-015 foils only made their debut at the Weymouth Speed Week and soon showed that they were noticeably quicker than the 0015 ones, enabling Joddy to have a run timed at just over 19 knots on Monday 3rd October.

The ventilation which had dogged us earlier has been virtually eliminated and one of our next tasks, with a new Westaway sail for 1995 is to see how well CALLIOPE can be made to fly to windward.

Calliope at Weymouth, 1994

The Sailboard's Bicycle Speed Meter

by Bob Spagnoletti

No speed sailor or yacht researcher should be without instrumentation! The sophistication possible depends on the craft, and the options for mounting sensors. For sophistication see the recent material by George and Joddy Chapman, for the cheap and cheerful read on.

On my windsurfer there is room for a water speed indicator but not much else. Commercial units are available, at a price, but none have proved satisfactory to date. (I have yet to try the latest Speed Watch which offers more features, it is currently advertised in the American magazines) From this starting point I decided to design my own around a cycle computer.

Cycle computers offer terrific value for money, they vary in the functions that they offer, but typically, for around £20 - 25, they give current speed, average speed, peak speed and distance covered. Choose one with the buttons on the front, the reasons will become clear later.

The cycle computer works by counting the revolutions of the wheel, from this and a knowledge of the wheel circumference it calculates the speed, distance etc. The wheel rotation is sensed with a reed switch and a magnet, every time the magnet passes the switch, the contacts close and one revolution is counted.

The water speed sensor I chose comes from Autonnic Research, it consists of a tunnelled propeller with a magnet and a reed switch. The sensor provides one pulse for every 26 mm travelled (approx), compare this with the bicycle wheel, one pulse every 2.2 meters! Fortunately, with relatively simple electronics it is possible to reconcile the two.

The circuit shown in Fig. 1 will divide the number of pulses by 2^n, where n is between 2 and 7. Dividing by 64 gets us close. Fortunately the cycle computer comes to the rescue with a variable calibration to cope with the different wheel sizes. This feature can also be used to make it read knots rather than mph.

The circuit given uses very little current and so it does not need an on/off switch and should run for a season on two alkaline AA cells. Disconnecting the sensor will prolong the battery life.

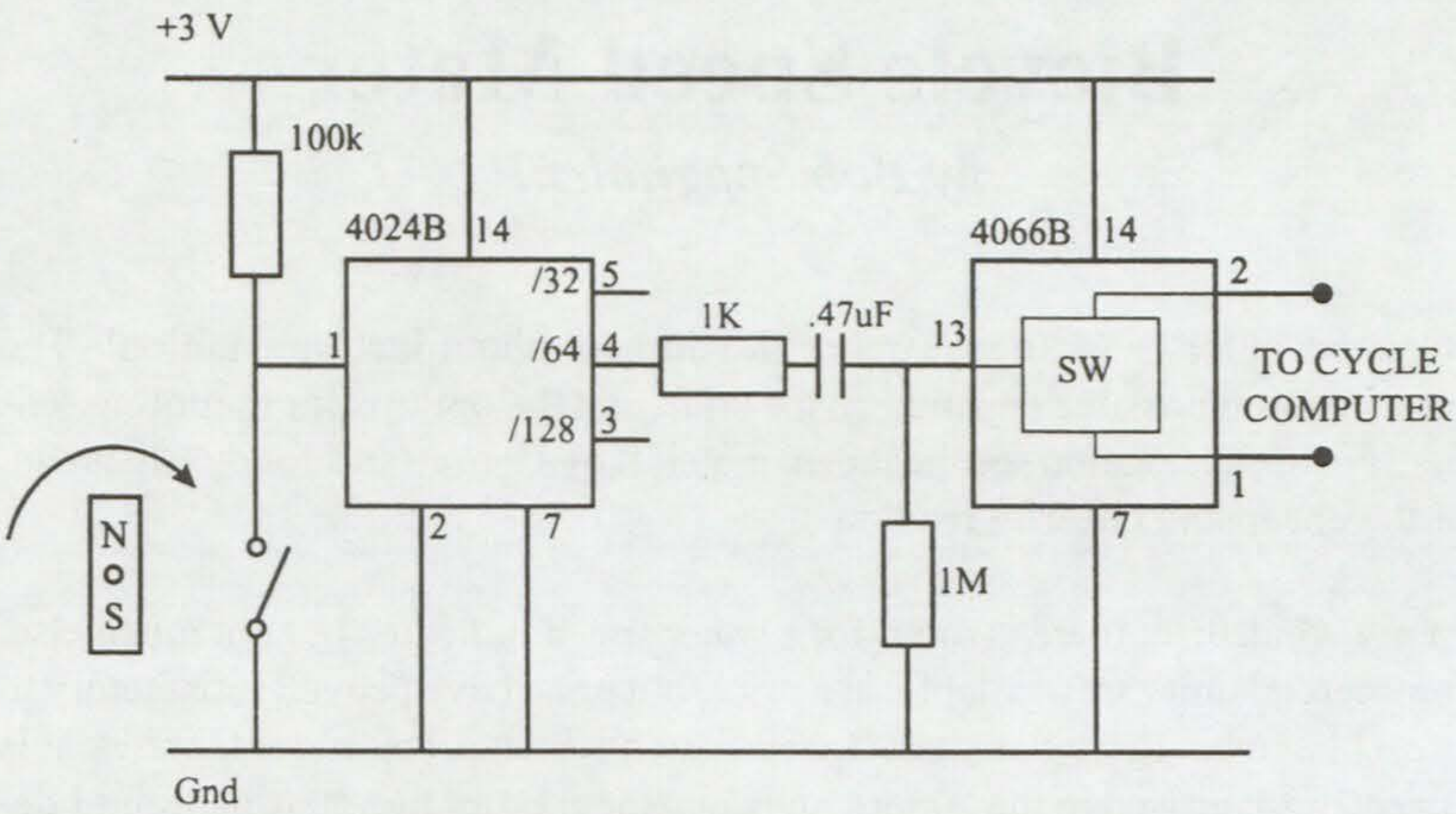


Figure 1. **Circuit Diagram**

The major constructional problem is to keep the water out. I used a metal die-cast box, with a sealed window to read the display. The window is cut from a PET soft drinks bottle and is sufficiently flexible to let you push the buttons to change functions etc. Note: Sea water will eat the monkey metal used for die cast boxes so some additional protection is required in some circumstances.

The box can then be sealed with whatever takes your fancy, however avoid silicone bath sealer which give off acetic acid as it cures (not good for electronic components). Special one part silicone sealers that don't give off acetic acid are available from electronic component suppliers. Fig. 2 shows the construction.

Seal every possible entry point for the water and then seal it some more! Testing can be done by putting the completed sealed unit in a basin of hot (not too hot!) water and looking for bubbles. Consider that cold sea water and barometric pressure will generally work against you!

On the water the first model leaked! Testing time of MK2 has been short to date but results are positive. If you want further details just contact me!

If there is a flood of interest I will consider designing a PCB to make the construction easier.

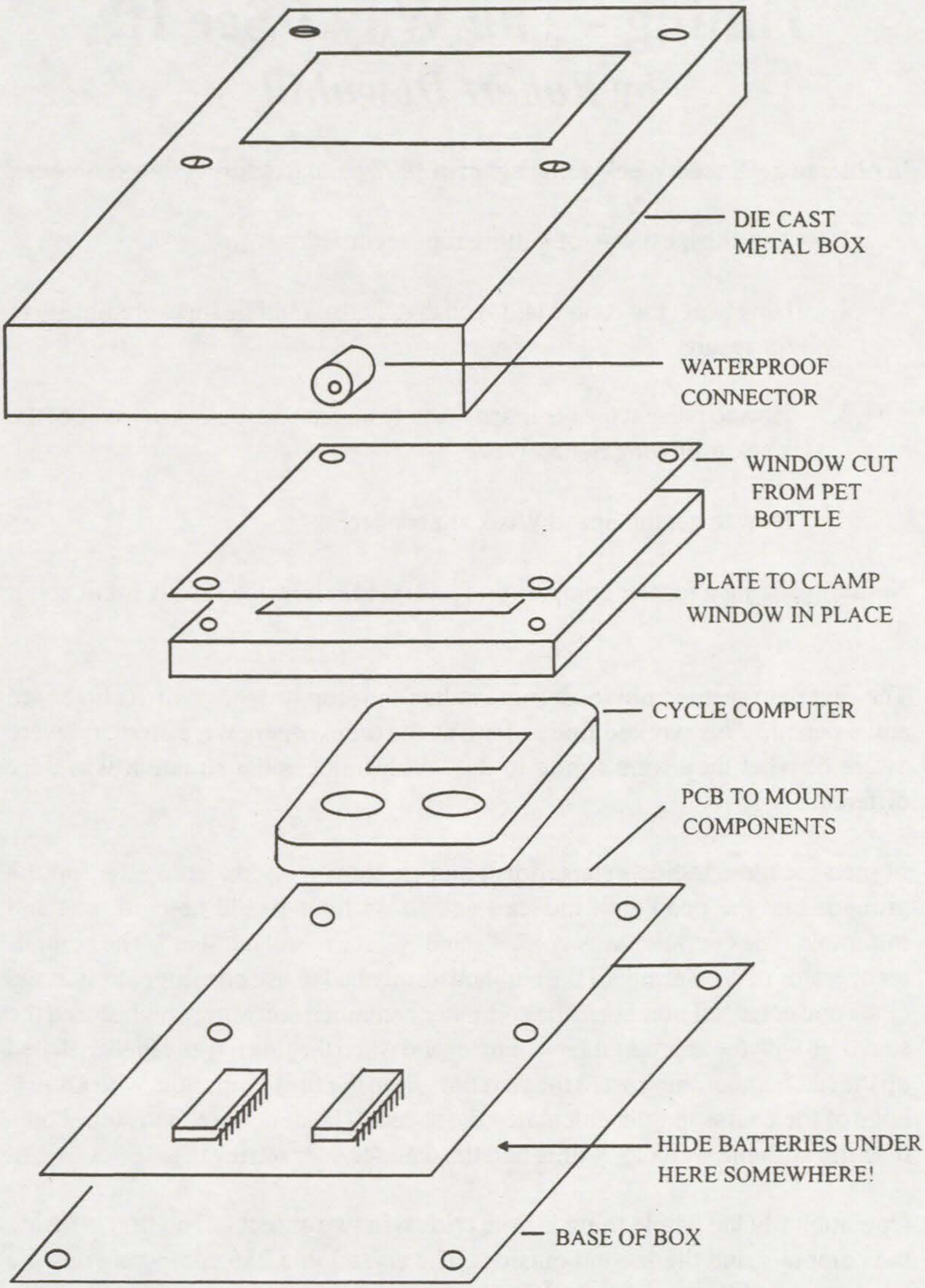


Figure 2. **Constructional Details.**

Timing - The Way I See It!

by Robert Downhill

In order to get Speed Week going again in 1992 I had to address four problems;

1. The cheapest way of getting runs recorded.

2. How to get the course laid such that there would be some credibility to the results.

3. How to present the results in a timely manner i.e. before the start of the week following Speed Week.

4. How to get the Speed Week atmosphere.

Naturally, being a former competitor, I had no idea how the R.Y.A. went about it.

The first item seemed obvious; some radios and stop watches with a clip board and a pencil. This worked fine as long as the timekeepers were alert and were aware of what they were trying to do. With trainees the situation was very different.

I opted for three radios - start, finish and clubhouse - and a computer, on the grounds that the people on the start and finish lines would be cold, wet and miserable. The operation was voice, "standby...start...sail number". The computer operator in the warmth of the clubhouse only had to use one finger to start the clock and enter sail number. The computer contained software which stored the start time with the appropriate sail number and when the finish was called matched up the sail number, subtracted the start time from the finish time and, with knowledge of the course length, calculated the speed. The data were then stored on a disc file with the wall clock time and the date for later retrieval.

Operationally the whole thing is time critical in two aspects. The first is inside the computer and the second outside. The crystal in a 286 computer runs the machine at 12MHz and the clock is a battery operated chip accessed by the Disc Operating System (DOS) on request by the program. The clock records seconds from the time the machine is switched on to 11 decimal places (eg 42709.994441073434 seconds). However, because the processor is working all the time doing housekeeping jobs, the accuracy goes down to 0.00546872 second (ie the clock changes only every 5 thousandths of a second). It is fairly obvious that while the computer is doing anything other than waiting for input it cannot accept data. This includes events such as writing to the disc, calculating the speed, even reading the keyboard and updating the screen. If care is not taken with the programming, the keyboard could be inaccessible to the operator for appreciable amounts of time. The second aspect is that the keyboard skills of the computer input person and the caller's voice communication skills have to be crisp, concise and very clear. We had one problem with a radio that was resolved when the caller started to speak into the microphone on the front of the set rather than into the battery on the back!

The next problem was how to lay a course with sufficient accuracy to make the thing realistic and, for me more importantly, do this from boats. There had to be more flexibility for wind direction than courses laid off the Chesil Beach with land based markers surveyed using electronic distance measurers (EDMs).

I already had the method of laying a course offshore using a sextant, providing there was a ground line of something like 500 metres and the ability to sight the ends of the course from the ends of the ground line. It was reasonably accurate but took about one and a half hours to do, even after training the course layers. The method was simple. First lay the ground line using a tape measure. Then the four angles were measured from the ground line to the two ends of the course. All this information was relayed by radio to the computer operator who ran a program which calculated the course length and set the various parameters to allow the logging program to do its bit.

When I tried this out in 1991 it was obvious that you needed good eyesight and, if it was raining, real determination. Additionally, there was no way of checking the measurements other than putting down another ground line and doing an independent check. Elapsed time 3-4 hours, by which time the competitors had gone home.

Luckily I located a company in the offshore industry who, after much persuasion, rented me a laser tape that had a range of up to 2000 metres to an accuracy of 0.5 metre. The laser tape measured the range in about 0.3 second, providing the target could be seen and the laser beam was held on the target while the ranging was done. At £30 per day the thing had to work! Fortunately the device focussed itself on to the target and to find the other end of the course was quite easy.

To lay a course from two stake boats the action was as follows. Both boats would head for the best place for the wind. The smaller of the boats would drop anchor and some discussion would take place between the people on the scene as to the best course direction. I think John Peperell had most say because he was always out sailing. Having decided a course direction, the larger of the stake boats would head off and the chap on the anchored boat called out the range until the course was at least 500 metres long. At this point the second stake boat would drop anchor and, when it settled down, the course length would be relayed to the base for entry in the computer. As soon as the length was entered the course was opened for business. If the wind changed one of the boats would up-anchor and move a bit; the range would be re-measured and the course opened again. I thought this was an improvement on what I had observed as a competitor as the course could be anywhere in Portland Harbour. Indeed, in 1992 we were over by the harbour wall to catch the north-easterlies prevailing that week. The course was about 3,000 metres from the Sailing Centre.

The problems in deep water are that the anchor chains are long and the opportunity for swinging is very real. However, in practice, the boats are remarkably steady except when undamped phugoid oscillations occur in some wind conditions and in shallow water. These effects depend on the shape of the stake boat and can be stopped by using three anchors. It is a real pain using three anchors and in practice the course is re-measured frequently and the computer updated on the fly. Naturally if there is only one person on the stake boat they have to be prompted frequently. This is always at the expense of relaying the wind speed back to base.

The start and finish lines are set at right angles to the course using sighting points on the periphery of the harbour.

Communications use three frequencies: Start to Shore: Finish to Shore: Boat to Boat. This is a total of 9 radios so everyone can hear what is going on. Additionally we use a rescue to shore frequency and of course the marine band for communicating with the Harbourmaster. I normally have 18 radios to hand with 4 frequencies available to us plus the marine band. It is a bit of a nightmare when the batteries start to run down and they have to be replaced - we never seem to have enough spare batteries. They are all rented.

When the system operates, the results are stored on a transaction file that has the time and date of the start of a sail number, the time and date of the finish of a sail number, and the results of the speed calculation plus wind speed and wind gust speed as measured and relayed by voice from the stake boats.

Should record breaking conditions occur, we have the ability to measure the course length for each run and also to give anyone the opportunity to have a say in the course direction and to give priority to whoever wants to give it a shot.

There has to be course discipline as there is no way we can handle bunching of competitors trying to race each other. We do have a multiple start and finish capability but it is seldom used.

Over the years the results analysis has grown like Topsy and it comes out raw, sorted, maximums, individual results, and for this last year I have included a ranking system for the windsurfers. This system was based on conversations with Mike Shaw and Dave White.

The last item, that of retaining the Speed Week atmosphere, was attempted by having a relaxed ground crew and no no-go areas. I hope it has been achieved.

So where are we now and where are we headed?

Over the last 5 or 6 years I have been experimenting with infra-red beams and lasers for the timing gates and the automatic acquisition of sail numbers. I could identify solutions to all the problems but cost precluded any consideration of this equipment for our use.

For instance, surveyors use a little yellow box which identifies its positon from another little yellow box to an accuracy of some millimetres, for £6,000 per yellow box,. Differential Global Positioning System (GPS) gets you within 2 metres for £2,000. Direct sighting using an EDM, the one I tried was a Sikisha (or somesuch) and was within a couple of millimetres for £11,000.

The biggest problem I can see is getting the sail number of a competitor as he/she goes over the transit line. Bar codes, infra-red bleepers, radio transponders, all have their limitations, mostly the inability to be selective. To put it simply, if a laser beam gets broken it is easy to punch a clock electronically at a range of 200 metres, but to get an answer to the question "Who's that?" is more difficult. A broadcast request would get a response from everyone. Recently I came across an electronically operated tagging system which was developed in South Africa that can be switched on and off by the interrogating scanner. The scanner has a range of 4 metres, so, with a bit of course discipline, something could be done with those. The entry price for a licence is £70,000 which includes a bit of demonstration kit. It is great pity the budget for whatever we do has to be less than £1,000 per year.

It was not until I twisted Joddy Chapman's arm and got a bit of kit for doing the auto infra-red gate with manual input at the stake boat via radio into the computer that we started to get somewhere. The cost, so far, on this one is about £1500 and an awful lot of time. With a laser gate in the kit instead of the infra-red beam we may be able to make the gate wider from the 22 metres of the infra-red unit to 50-100 metres. We still have a way to go!

One day, in, I hope, the not too-distant future, someone is going to ring me up and say "What do you think of this?" and produce all the features to satisfy the R.Y.A., the B.W.A., the P.B.A., the London Marathon and the Olympic Games all in three boxes for £500 - and a sponsor to pay for it.

Walker Wingsail Wins £1.5 Million Libel Award

Copied from MULTIHULLS Magazine (USA) with their kind permission and that of John Walker.

The British monthly magazine, YACHTING WORLD, in its February 1993 edition, published an article written with such malice and hostility about Walker Wingsail System's revolutionary trimaran, BLUE NOVA, that a jury awarded the second highest amount * in the history of Britain's High Court.

The judgement has three parts: portion of the £1,485,000 to John Walker, Chairman of Walker Wingsail Systems PLC, £450,000; to his wife Jean, Commercial Director of the company, £35,000; and £1 million to the company. YACHTING WORLD also faces an estimated £750,000 legal bill.

During the five-week court proceedings John Walker described his rage and disgust at the magazine's review. He said that he had to endure "ribald and snide comments" from people visiting his stand at the London Boat Show, which coincided with the publication of the damaging article. YACHTING WORLD has a circulation of about 30,000 and is celebrating its centenary.

Mr Walker contended that the article reviewing his design "had shown complete incomprehension of the design and was littered with inaccuracies."

The defendants: Matthew Sheahan, the magazine's technical editor; Andrew Bray, editor; and IPC Magazines, the publisher - claimed that the report was justified, it was a fair reflection of the yacht's performance in a sea test.

But the jury, during its four hour deliberation, accepted John Walker's assertion that the magazine threatened to ruin his business. He said it seemed "to be a bid to drive our company out of existence."

The chronology of events started with Mr Sheahan arranging a test sail of BLUE NOVA on Plymouth Sound in November 1992. John Walker was excited, and naively hoped that the article would provide some long-awaited positive publicity. Instead, he was horrified when he picked up a copy of YACHTING WORLD at the London Boat Show and read the scathing attack on his design which asked: "Is she an impressive feat of ingenuity, or an unwieldy white elephant ?"

* *The highest award was £1.5 million to Lord Aldington against Count Nikoli Tolstoy and Nigel Watt in 1989 over a leaflet they published about the Lord's war conduct.*

The second highest jury award in British legal history will be appealed, according to David Eady, QC, the magazine's legal counsel.

After the trial, John Walker wrote the following in a three page letter:

"The very substantial damages awarded to us by the jury in our recent High Court action have quite understandably dominated the headlines. It seems sensible, therefore, to set out at least some of the central concepts argued in more than a hundred hours of evidence given during the five-week trial.

"The reason why we brought, and steadfastly continued the action is that an unfair and hostile report was published without the slightest opportunity to correct or even comment on misconceptions or errors before printing.

"As the evidence unfolded, the case became progressively more and more powerful that the boat performance-testing methods used by YACHTING WORLD are fundamentally flawed. Mark Gatehouse, our expert witness, rather forcefully pointed this out, his colourful phrase being "totally duff."

"While both racing and cruising yachtsmen can find True Wind information calculated on board useful, a boat-testing journalist has no need for this. He should simply log into a computer literally thousands of simultaneous 'sets' of Apparent Wind Speed, Apparent Wind Angle and Boat Speed readings taken directly from the transducers, raw and unprocessed, and then process then on dry land as part of the preparation for publication. This is the technique used by Mark Gatehouse and Matthew Cowpe in the tests conducted for Walker Wingsail Systems plc. Simple sorting and averaging will then produce polar curves 'untouched by human hand.'

"By contrast, the YACHTING WORLD technique contains two serious defects. First of all, it uses the on-board processing of a Stowe instrument set, with all the averaging delays involved in that. If you instantly stop the spinning anemometer cups with your hand, it takes a full 8 seconds before the display reading has fallen to zero. This is no criticism of the Stowe instruments, which are sound equipment for the cruising yachtsman.

"Secondly, YACHTING WORLD passes the true Wind Speed, True Wind Angle and Boat Speed values processed by Stowe through the four filters of the Tacstar system. Tacstar is a splendid program for any individual owner wanting to tune up his boat, where he records a set of polar values, makes some adjustments, and then goes out to see if he has made any improvements. It is <u>not</u> designed for comparing different boats and is, in fact, capable of being operated so as to be seriously misleading when used for this purpose. The four filters are:

- True Wind Angle up to a maximum of +/- 20 degrees, e.g. any angle from 20 - 60 degrees can be accepted as 40 degrees TWA.
- True Wind Speed up to +/- 25%, e.g. any speed from 7.5 knt to 12.5 knt can be accepted as 10 knt TWS.

- Percentage Increase (maximum allowed) 1%-100%.
- The Time Period that a boat's speed must be maintained before acceptance can be set to anything from 10 seconds to 120 seconds.

"By setting the filters to different values within their very wide limits before testing, it is obviously possible to produce either favourable or unfavourable results from any given set of data. For example: if the True Wind Speed filter is set to +/- 25%, then 7.5 knots TWS and 12.5 knots will both be accepted by Tacstar as 10 knots TWS. Since wind energy varies as the square, a boat sailing in 12.5 knots TWS (12.5 x 12.5 = 156) will have almost three times the wind horsepower of the same boat sailing in 7.5 knots of TWS (7.5 x 7.5 = 56). Tacstar is capable of printing two very different, but equally impressive-looking "10 knot TWS" polars, one looking speedy, one sluggish. Each filter can be just as powerful as that, and it may be that the jury's decision on the trial was influenced by evidence that three of the four filter settings "could not be recalled" even though they had had to be carefully selected and set before testing BLUE NOVA.

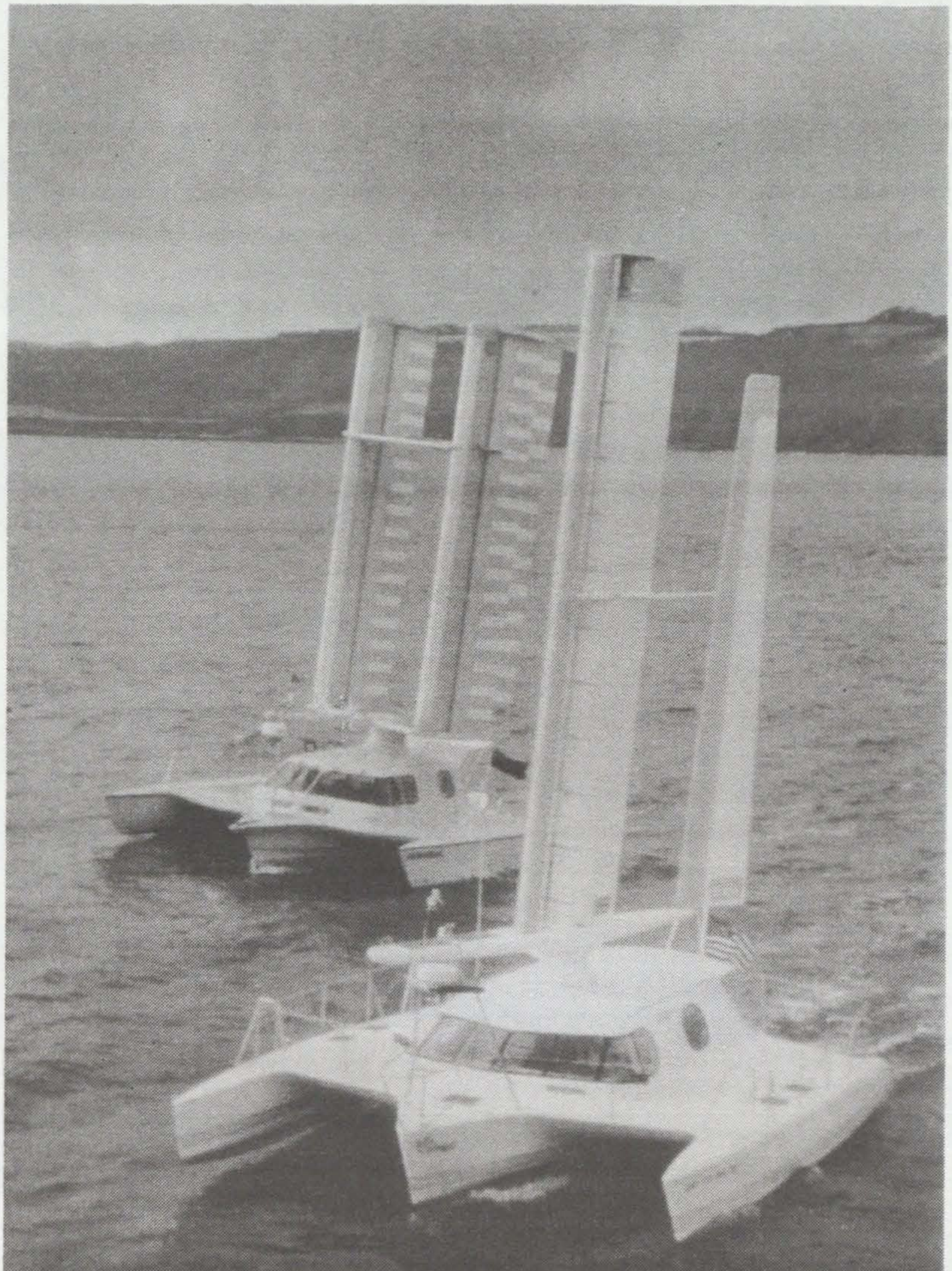
"There were, of course, more or less complex elements in the long trial. The full transcript would surely run into hundreds of pages, but it seems clear that a boat-testing journalist can exercise tremendous power over the builder, that power should, for everyone's sake, be exercised with scrupulous care and evenhandedness.

"The defendants maintained that BLUE NOVA, even when she was much lighter than her present displacement, and with her unraked wingsail significantly more powerful than it is now, could not have achieved "14 knots in 10 knots of wind" or "almost 14 knots at 30 degrees to the apparent wind in a stiff sailing breeze." They argued that our instruments must have been inaccurate at the time.

"Fortunately for us, PC Clive Clayton of the MOD Water Police just happened to have clocked BLUE NOVA at 13.5 knots at 45 degrees to a Force 5 wind, when our own instruments were reading just under 14 knots, on the 26th October 1990. This was the first sailing trial, and our experiences on that day formed the basis for the concept brochure text.

"Professor Austyn Mair, one-time Head of Engineering at Cambridge University, has written a report which confirms, that in his opinion PC Clayton's evidence can also be extrapolated to support "14 knots at 90 degrees to a true wind of 10 knots." His report was submitted to the defendants, but a decision was taken not to call him as a witness, in order to keep the level of technicality down for the jury."

Editor's Note;
We understand that the appeal may come to court in November 1995.



ZEFYR and BLUE NOVA

Walker Wingsail Systems' ZEFYR leads BLUE NOVA as they are about to come on to the wind - at a leeward mark?

Resonance as a Measure of Sailboard Stiffness

by B Cartwright and G Ward

Introduction

This paper describes the simple measurements carried out on sailboards to demonstrate that the relative stiffness of a single board may be detected in a matter of seconds. This may have considerable merit in measuring boards for international one design class events.

Theory

All mechanical structures exhibit a natural frequency when struck with sufficient force. A tuning fork is a perfect example of a structure which has been designed to resonate at a specific frequency. The shape of the fork, the materials it is made from and how it is struck determine the frequency at which it will vibrate.

The resonance of other structures may not be quite as noticeable, but with the aid of the appropriate equipment, the resonance of almost any structure, from a pin to a tall building, may be measured.

The critical factors which determine the resonant frequency of a structure are;

1. Shape
2. Mass
3. Stiffness of the material

These quantities are all in the equation for the natural frequency of a simple mass hanging on a spring as follows;

$f = 2\pi(k/m)^{1/2} =$ natural frequency in Hertz (cycles/sec)

where; k = the stiffness of the spring, in Newtons/metre

m = mass in Kilograms

Here we see that an increase in mass, m, will lower the resonant frequency. An increase in the spring stiffness, k, will increase the resonant frequency.

The shape in this case influences the stiffness of the spring. Increase in shape doesn't mean much, but an increase in stiffness does.

Along with these primary factors, the following factors will influence the resonant frequency;

4. The distribution of mass
5. The 'damping' (how quickly the vibration stops)
6. How the structure is struck
7. How the structure is supported

In short, a more spread out mass will lower the natural frequency. This is because, compared to a compact structure, its inertia is greater and this requires more energy to move it, ie to make it vibrate. (Imagine a see-saw with two people sitting near the centre - it can be made to rock quite quickly. If the two people sit at the ends, it is much more difficult to move the see-saw at the same rate. This is why sailors like to reduce the mass in the ends of their boats.)

The damping becomes noticeable only when it is so great that the vibrations barely oscillate. Increased damping reduces the natural frequency.

As a structure vibrates, some parts go up and down (or sideways) where other parts are stationary. The place of maximum amplitude is termed a 'node', and the stationary points are 'antinodes'.

In the vibration of a simple beam supported at each end, ie a plank of wood on two trestles, the middle will be a node and the ends will be antinodes. This vibration will give the lowest frequency for that beam and is called the first mode.

If the trestles are moved in one third from each end, this forces the antinodes to be at these points. There will now be three nodes; one at the centre still and one at each end. This is the second mode of vibration and is higher in frequency than the first. As the 'mode' increases, so does the number of nodes and antinodes, and the frequency - but the amplitudes become smaller.

If a structure is hit at a **node** it will vibrate freely at its lowest possible frequency, until the damping kills it. If the same structure with the same supports is struck with the same force at an **antinode**, almost no vibration will occur at the previous displayed frequency. Instead a higher frequency will be excited that has a node near to the point of the hit.

OK, enough of the theory. How do we relate this to sailboards or yachts?

Applying the Theory

So far we have discussed the resonance of a mass on a spring, and a beam. Neither of these behave well as a boat. The case of a sailboard has been chosen because it resembles a simple beam with some 'shape'. Being similar to a beam allows the natural frequencies to be easily approximated as well as measured.

According to the previous theory, if the mass of two 'identical' sailboards is different, then a difference in resonant frequency should be detected. Similarly with the stiffness.

In practice a stiffer board would be better to sail, as not as much energy would be spent in vibrating the board. Conventional measurement techniques measure only the physical dimensions and the weight of the board. Hence it is possible that someone could disguise a 'modified' stiffer board to look like a conventional production or one design board, and have it pass the measurers.

Experiments

In our experiments we used two identical boards of the F2 265 Sputnik World Cup Edition type. One of the boards was brand new, and the other board had been used extensively. The boards were constructed from woven fibreglass with a foam core and are considered to be identical in manufacture. We must express our thanks to F2, Dave White and Colorsport Ltd for the loan of these two boards.

We were also fortunate to use the vibration instrumentation of the Imperial College Department of Mechanical Engineering, courtesy of Dr Peter Cawley who expressed interest in this work.

Both boards were measured with no attached fittings. ie fins and mast step were removed.

As neither of us had measured the vibration response of a sailboard before, the first few experiments were purely trial and error to get a feel for the situation.

Vibration of the board was measured with small accelerometers, held to the board with double sided tape. (An accelerometer is a piezoelectric device which generates an electrical signal in response to acceleration. The accelerometer signal can be integrated electronically to arrive at a velocity or displacement signal if required. For the purpose of frequency measurements, the response is identical in acceleration, velocity or displacement.)

The electronic signal was displayed on a Bruel & Kjaer Spectrum Analyzer. This analyzer can display either the time trace of the signal as it happens (like an oscilloscope trace) or the frequencies present in the signal. (The axis of the display in this mode are frequency along the horizontal axis and amplitude on the vertical. Thus a pure vibration at one frequency would appear as a single vertical line at the given frequency.)

One board at a time was placed on foam blocks to isolate it from the ground. The accelerometer was taped on in varying places and the board struck with the open palm. The accelerometer and support blocks were moved to observe the effect of location.

Results

As discussed earlier, the response of a beam depends on where it is hit and where it is supported. It was quite easy to hit the board at a node, ie one end, and get a large response. The same response could be achieved time after time. Similarly, if struck near a antinode, the dominant frequency and amplitude would change to the next highest mode shape.

By moving the support blocks various lower modes could be suppressed or enhanced. Thus we were happy we could measure the resonant frequency of a board with some reliability and repeatability.

Next was to see if a difference could be detected between old and new boards.

The table below summarises the results.

Board	Comments	Natural Frequency (Hertz)
Old	no attachments	54
New	no attachments	57
Old	with fin	52
Old	with fin and extra mass in centre	44
Old	with fin and extra mass at fin	15

Note : each value represents the average of 3 or more tests.

The results indicate that a definite variation in resonant frequency of the two boards was detected. The matter remains to determine exactly what produces the difference.

More extensive tests have since been carried out on several other types of sailboard, and the results will be reported later.

Discussion

The tests indicated the older board to have a lower resonant frequency than the new board. It was mentioned earlier that two things primarily influence the resonant frequency - mass and stiffness. (Shape is identical in this case)

A lower stiffness could produce a lower frequency. So would an increase in mass. It is interesting to note that a 5% decrease in stiffness has the same effect as a 5% increase in mass.

Lower stiffness is a plausible explanation, as the board has been used, some over stressing might have occurred producing local breaks in some fibres. Also, heavy usage might result in some delamination of the core/glass bond, thus producing a weaker structure.

Increased mass may also be possible, for if the board had been used recently it may have absorbed water which had not dried out before the tests. We regret that we did not accurately measure the mass of each board in these tests.

For these tests the results are not decisive. But what should be kept in mind is that mass is easy to measure accurately, and so it is possible to determine how much effect an increase in mass would have on the frequency. If mass had been measured, we could positively identify the stiffer board.

From the other results we observe the effect of increased mass by way of the fin and a lump of metal. The fin is a very light plastic structure, but its placement near a node (the end) dramatically influences the measured frequency. A difference in the mass of the fin would also be seen in the overall resonant frequency of the board.

A demonstration of the distribution of mass was achieved with a lump of metal. Initially placed in the centre of the board, it brought the frequency from 52 Hz down to 44 Hz. But shifting the same lump of metal from the centre of the board to the tail end brought the frequency down to a low 15 Hz.

This last demonstration highlights that through simple vibration measurements it is possible to detect if a board has been made lighter at the ends, yet still retaining the 'correct' mass.

Conclusion

These initial experiments have demonstrated that simple measurements of the natural frequency of a sailboard, combined with an accurate measurement of the mass, will enable the board stiffness to be determined.

Although an increase in stiffness may be offset by an increase in mass, the benefits would be lost if this was employed. Further, mass can easily be measured and accounted for in simple structures.

In a practical application it is not so much the specific stiffness which is of interest, but more of identifying which boards deviate from the norm. In this sense vibration measurements could be very valuable.

The placement of the support blocks and the accelerometer was shown to be not critical in determining the resonant frequency. The dimensions of the sailboard results in the distance between the lower mode antinodes being one metre or more. Thus placement of the blocks and accelerometers needed to be within only 300mm or so of the nodes to produce reliable results. For formal measurement procedures these locations need only be accurate to within 20mm. Each vibration test requires only a minute to collect enough data to determine the frequencies.

In view of carrying out these type of measurements at a large regatta, the equipment developed for the industrial application of machinery vibration analysis could be utilised without any modification. Such portable analyzers exist which can acquire up to one thousand test results in a robust portable machine smaller than a lever arch file. This machine then transfers its data to a personal computer which can average all the data acquired and immediately highlight those which deviate by a preset amount.

Extending this theory further could see the study of vibrations in panels on larger one design boats. By employing the same technique of identifying critical areas for measurement on a boat, collecting vibration response data from a number of boats could once again identify those boats which have been stiffened beyond the rules.

The capabilities of vibration analysis techniques in the control of one design yachtsand sailboards have been demonstrated here. Further work will be required to verify the reliability and sensitivity to the traditionally conservative sailing populous. But be warned; technology is once again moving in on those who dare to bend the rules.

The authors would be pleased to receive constructive comments and thoughts on this topic.

Conclusion

To my great shame, it was not until the Summer of 1993 that I first read 'Design for Fast Sailing', by Edmund Bruce and Harry Morss (AYRS 82). My initial reaction was excitement that these two had done so much, so long ago, to develop the tools to measure and to analyse yacht performance. Later I began to wonder why I could not remember reading of any more recent innovations in AYRS publications.

I felt sure that the developments in modern electronics and the ready availability of exotic components to the amateur constructor must have stimulated the production of ever more sophisticated measurement equipment. But when I looked into back copies of AYRS I discovered that my memory had not failed me, there were no such reports.

Why had there been no reports? I knew, from the survey conducted by Fred Ball, that many members have a background in electronics. Some people suggested that the commercial equipment was so good that there was no scope for the amateur. But surely the amateur could improve on the cost?

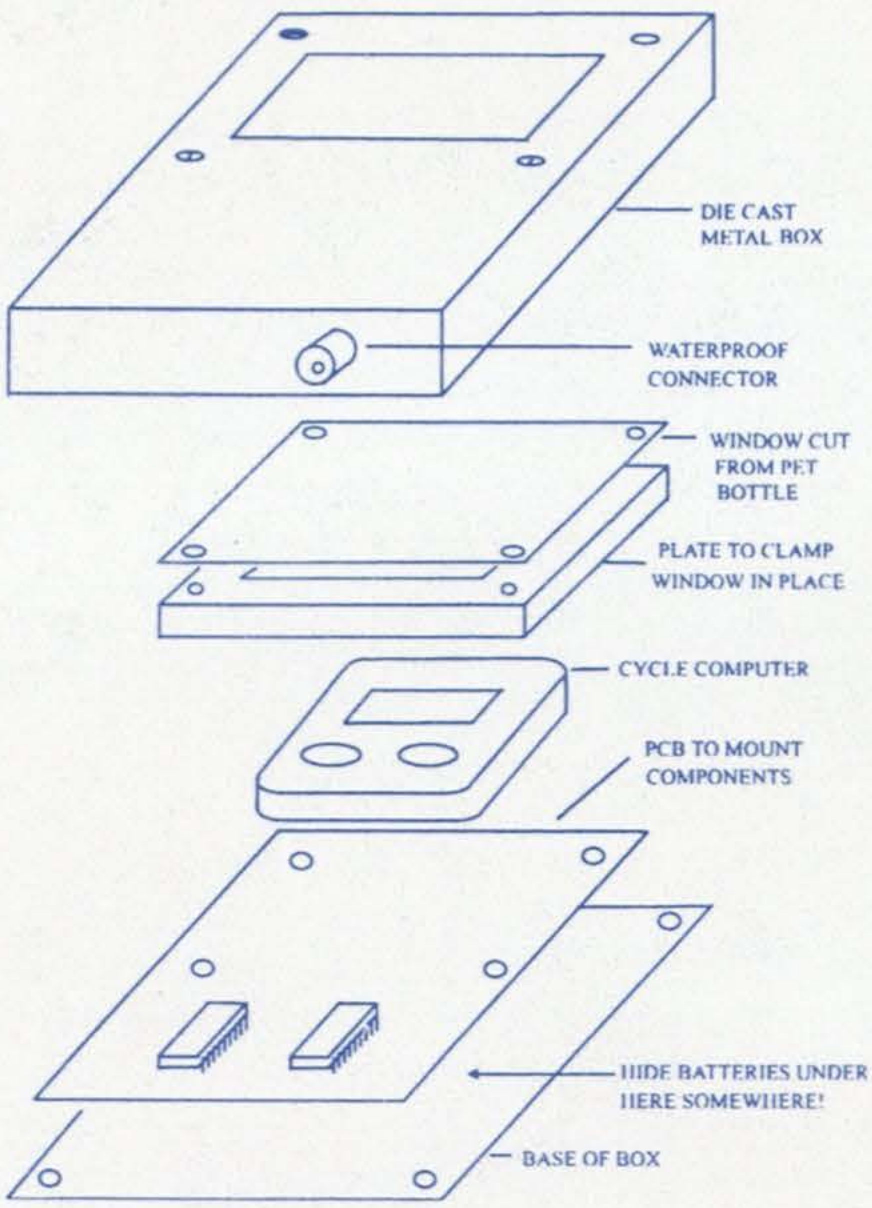
Later that year, I met George and Joddy Chapman at the 1993 Weymouth Speed Week and discovered that they had been developing a performance monitoring and analysis system for Calliope. I also met Bob Spagnoletti, who showed me his adaptation of the cycle speed meter. They were immediately pressed into producing reports and I soon had the beginnings of a publication.

My problem then was how to build a publication around these two reports. While I was waiting for more material, other articles, on other topics rolled in and kept the publications going. Meanwhile I was feeling more and more guilty about sitting on the articles from George, Joddy and Spag. Eventually, George, I suspect despairing of his article ever being published, offered to take on the editing of this publication.

There is no justice in this world. As a result of my lethargy, we have ended up with the best qualified person editing (and writing a goodly part of) this issue.

This is an important publication on an important topic; the first we have produced on this topic for twenty years. George and Joddy have shown the practical value of such equipment by their victory in the 1994 Speed Week. I hope that it will not be another twenty years before we are able to publish more on the subject. Get the soldering irons warmed up!

Tony Kitson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WATERPROOF
CONNECTOR
WINDOW CUT
FROM PET
BOTTLE
PLATE TO CLAMP
WINDOW IN PLACE
CYCLE COMPUTER
PCB TO MOUNT
COMPONENTS
HIDE BATTERIES UNDER
HERE SOMEWHERE!
BASE OF BOX

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