CAD-CAM in multihull design

Computer Aided Design (CAD) and Manufacture (CAM)

Tremendous advances are being made in Computer Aided Design and manufacture (CAD,CAM) and most important for the normal user, smaller and cheaper systems are available that will run programs previously only available for very large and expensive machines. Another essential change that has occurred is that the new generation of micro computers are very fast in operation, and extremely easy to use. These two factors are vitally important if the computer is to be used as a serious dynamic design tool. It is not enough to have a very clever program a it is inflexible and slow to operate. The program will be used in direct proportion to its speed of operation. If it is fast and versatile it will become an incredible dynamic design medium, if it is slow it will be nothing more than a sophisticated calculator for speeding up laborious calculations. If a computer program is to be used as a design tool it has to be versatile, and it has to have potential beyond that initially visualised by the programmer. Why is this so?

Firstly, the programmer is very often not a designer. This means that he will not necessarily be able to anticipate every use that the designer may require, although by means of good feedback and follow-up with program updates, this can be overcome. Secondly, and this is probably the most exiting factor associated with CAD, in using the program the designer will discover new areas for design development. He will suddenly realise that he can make computations never before possible -this will generate new ideas and possibilities -the solution to these computations will, in turn, lead to new ideas and the computer has become a genuinely creative design medium, and it has ceased to be a sophisticated calculator. It is virtually impossible for the programmer to anticipate these developments, so it is essential that he creates as flexible an environment as possible for the designer. An environment in which creativity can flourish. Another much ignored factor is the time it takes to learn how to operate the system. The cost in time, for instance, of a complicated program on a slow computer, could easily double the effective cost of the software, and this cost is incurred each time someone new has to learn how to run the system.

MacSurf

It was these factors that Andy Mason of Graphic Magic had in mind when he chose the Apple Lisa, which has now been superseded by the Apple Macintosh, as the ideal micro for developing a suite of programs for yacht designing, covering all aspects of design problems related to the hull and deck surfaces. I must confess, 1 was sceptical about the MAC when I saw Andy's prototype program about 2 years ago. I was very concerned about the screen size, and the resolution of the drawings. It seemed to me that it would be difficult to visualise the boat on such a small drawing (the screen on the MAC is 160 x 100 mm) when I was used to working on drawings of Al size or larger. (Al is 594 x 841 mm). Also, while it was easy to draw a boat, it was very difficult to draw the exact boat you were trying to achieve, and very complicated to input an existing design.

Furthermore, I already had an enormous number of engineering and other programs written and running on another micro, which we were very happy with, and I was not keen to have two types of computer in the office, because it meant that everyone would have to relearn how to use the new one, and we could not contemplate rewriting all our software for the Mac. I was going to have to be entirely convinced before buying another computer. In fact relearning has not been a problem because the Mac is so incredibly easy to use, and the two machines complement each other. At that time the program Andy had written allowed you to draw a boat on the screen and plot it out, you then had to measure all the hydrostatics in the old way - by hand. We were still in the realm of the useful calculator. I suggested to Andy that the vital factor would be to link a page of calculations that could be customised by each individual designer to the drawing, so that as the hull was manipulated on screen, all the hydrostatic information would be instantly available. About a year later I had a phone call from Richard Parkes of lsland Computer Systems. "I have the new version of MacSurf from Andy, wait until you see it, it will blow your socks off. It did.

Designing with MAC & MacSurf

With any computer yacht design facility it is essential that the designer has complete freedom of control over the hull shape. Some earlier attempts to use microcomputers for hull design had restrictions on the final shape that could be obtained. MacSurf allows virtually any conceivable shape to be drawn. With a grid of 16 x16 control points extremely complicated hull shapes can be generated with reverse curvature and hard chines. This control over the surface is particularly useful when designing certain multihulis, for instance, which have unusual hull sections, and in particular where the decks are being designed with much attention to airflow, as to the underbody is being designed for water flow. User friendliness is essential. Otherwise, a the program is slow to run, there will be no incentive to experiment, and the one real advantage of having the hull on the screen will be lost. MacSurf gets around this by using the inbuilt graphics and user friendliness of the Mac to great advantage and also by allowing the designer to change the precision at which the hull is drawn. This means that early experimentation with the hull shape can be done very fast at low precision, and as the final stages of the design are reached the precision of the drawing can be increased to provide virtually perfect curves. These can then produce 100% accurate and fair off- sets, and computer plotted frame drawings at any scale.

Versatility

One of the great restrictions in many computer programs is that in order to keep the program within a reasonable size, one often finds that the versatility for the user is greatly restricted and, yet, in order to utilise the full potential of this kind of dynamic design medium the more access the user has to the variables in the program, the further each individual will be able customise the program to his own needs. In this respect MacSurf is excellent and over the period of nine months that I have been using the program, many more uses have come to light than I had originally anticipated in common with my previous experience of all good programs. Furthermore, I have been able to write in my own hydrostatic analysis of the hull, on the calculations spreadsheet, with the secure knowledge that no other designer has the same information.

Screen size

As mentioned previously, one aspect of the Mac that concerned me initially was the size of the screen and, hence, the size of the boat image that I would have to work with on the screen. At first it appears that it would be hard to visualise the true shape of, say, an 80' boat when the profile an the screen is actually 6" long, however, with the zoom facility and the knowledge in the back of one's mind that the lines are perfectly fair, one soon becomes completely confident in producing any shape in the secure knowledge that the final plot will be exactly as anticipated. When viewing the drawings shown later in this article, keep in mind that these are limited by the resolution of the screen, and are in fact perfectly smooth fair lines. Any of these drawings can be plotted at any scale. The drawings will then be better than can be achieved by hand, and all the lines are smooth

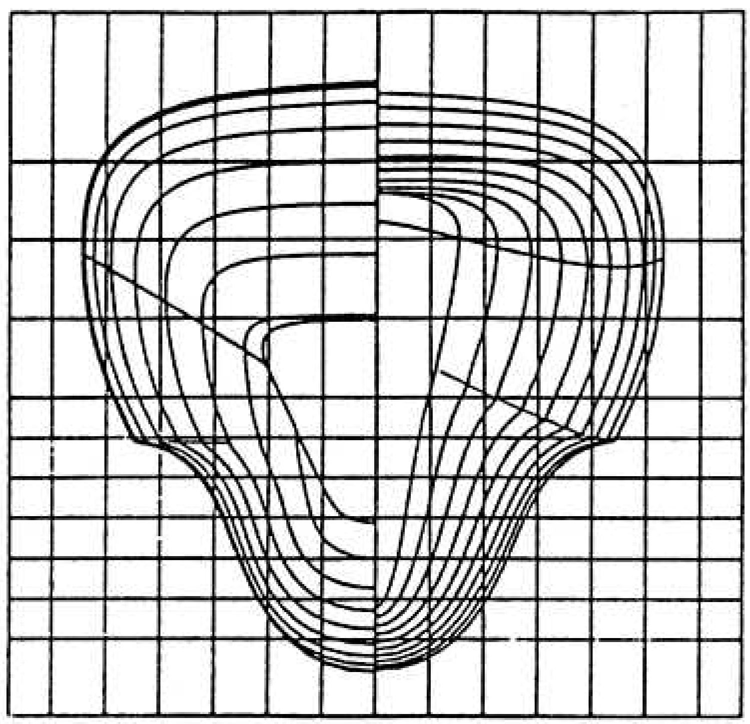


Fig. 1a. Computer plot of 50 ft catamaran sections

and fair.

Fig la shows the plot of the hull and deck sections of a catamaran.

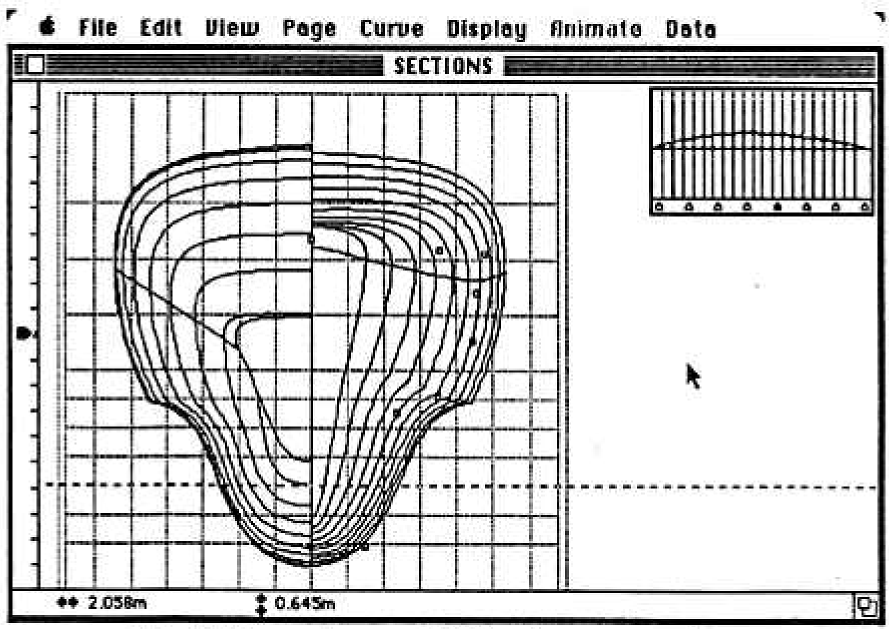


Fig. 1b. Screen Image of 50 ft catamaran sections

Fig Ib shows the same image that would appear on screen.

MacSurf Features.

Versatility in modifying hull shapes.

The secret of the Mac is that moving a pointer around on the screen by means of a mouse performs virtually all commands that control the computer. All operations are highly visual and are in as simple a form as possible. This system is used in MacSurf in many, sometimes amusing, ways. Modifying hullshape is very simple. The shape of the hull is controlled by a network of points that hold the surface in position, rather like the weights on a drafting spline. When working on the profile, for instance, in order to change the shape of the hull, the pointer is merely positioned on the appropriate control point, and the point is pulled into a new position. In about 3 seconds (depending on the precision of the drawing) the complete hull is redrawn in 3 dimensions. And it is perfectly fair. If you then choose, in about another 30 seconds, all the hydrostatic information on this new hull can be displayed on the screen. When you consider that this same operation could take 2 or 3 days by hand, it is easy to see that in the time it previously took to draw and analyse one hull, you could do the same to approximately 100 hulls. (Given the fact that you will need time to think about each permutation.) But, this is still only fast calculating - the program goes much further than just saving time.

On screen dimensioning

On screen dimensioning means that the coordinates of the pointer, which is controlled by the mouse, are displayed on the screen at all times. This means that measurements can be taken directly off the drawing on the screen at any scale.

3D Animation and Perspective

A very useful feature for viewing new or unusual shapes is the perspective view. The on-screen picture can be rotated through any angle and can also be animated so that the hull can be rotated rather like a movie film. This gives a designer and his client a much better opportunity to visualize the shape of the boat than is possible with a conventional 2D drawing.

Zoom

The zoom feature allows one to inspect any partof the hull at any scale to slightly larger than life size; this takes a little getting used to because when you zoom in on one part, you cannot see the whole of the hull. At first I was not confident that the changes made while zoomed would produce a fair shape on the rest of the hull, however, there are several simple rules to follow in the way that the control points are positioned in relation to each other, that always will produce a fair shape. Once these are known, working between a zoomed image and the larger view is very simple indeed.

Bulkheads and Section drawings

Macsurf gives the option of placing up to 20 stations anywhere along the hull, at any one time on the screen. This means that once the hull is designed, all the bulkheads and sections can be plotted at any scale, up to full size. This greatly speeds up the design process since there is no need for the time consuming process of taking sections and bulkheads from the lines plan and they can be plotted perfectly at the press of a button. One of several automatic features that can be selected is to space the sections evenly along the waterline.

Lofting

It is now possible to obtain computer drawn full-size frame drawings for the hull, directiy from MacSurf. This saves time for the builder, not only because he does not have to perform the laborious process of lofting the hull from the table of offsets, but also when the mold is built, using perfectly fair frames it greatly reduces the building time and, of course, a better hull will result. To give an example of how this can pay off in practice - recently 4 men built the complete fully-planked (double diagonal) hull mould for a 50 ft hull of my design, in two and a half weeks from receipt of the full-size drawings. Normally they would probably only have finished the lofting in the same time.

Hydrostatics.

MacSurf takes a large number of measurements directly from the hull currently on the screen and allows the user to set up all the relevant hydrostatic equations in a spreadsheet. This calculations page can be called up and recalculated at any time. A recalculation approximately 30 seconds to 1 minute on average. Therefore it is very fast and easy to develop new shapes and analyse them instantly. Once a hull has been finalised, further in depth analysis can be carried out by moving the waterline to any position, or by changing the fore-and-aft trim, or angle of heel, to any angle and recalculating the hydrostatics. The information from these incremental changes can be immediately fed into a graph-generating program such as Cricket Graph to produce a model of dynamic change of any hydrostatic variable. Alternatively, the hull and deck form can be loaded into MacHydro (an as- sociated program by Graphic Magic) and the hull can be floated free to trim at a series of heel angles, or displacements. And, again, graphs of all variables can be obtained directly within MacHydro. The resulting set of images can be animated (like a movie film) so that the hull can be viewed rolling and trimming exactly as it would in reality. This facility opens up a completely new field of research and development for the average yacht designer which was previously virtually impossible to carry out, due to the enormous amount of time it would take to generate even one set of accurate data points with a change in trim, heel or waterline. Loading existing hull shapes into MacSurf is greatly simplified by the facility to set markers on the screen. This means that a profile (for instance) can be defined, and then the curve is fitted to the markers. Depending on the complexity of the hull shape, it can take between 3 and 8 hours to input an existing hull. Once in MacSurf however, all the data analysis is available. It is also extremely easy to modify the shape, and to scale a to any size. This means, for instance, that I can now offer customised lines plans for each boat to account for moving engine position, or even changing from a two-engine installation in a cat to having a single outboard.

Using MacSurf

Some examples of problems that I have studied using this facility have already answered many questions, and at the same time have opened up several exciting new areas for further study. For instance, we have been able to study the effect on the hydrostatics of the Spectrum 42 Catamaran of adding a bulb bow. A very accurate bulb was drawn by concentrating 20 stations in the vicinity of the bow, as shown in Fig.2.

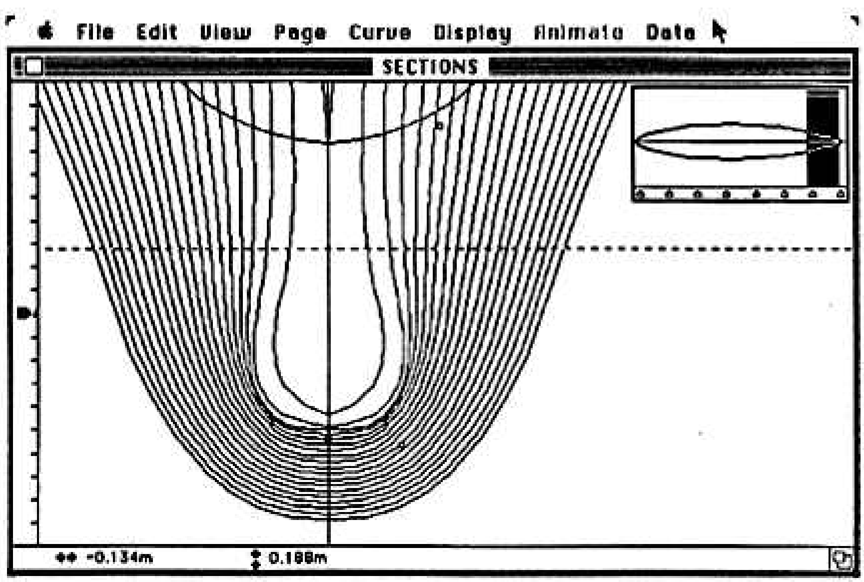


Fig. 2. *Spectrum 42* with bulb bow.

The fore-and-aft trim of the hull was varied in one half degree increments, and the hydrostatic information obtained at each angle of trim, to emulate a pitching motion in a seaway. Comparing this to a similar analysis on the standard Spectrum 42, which has no bulb, we were able to conclude that there was a negligible difference in the way the two boats perform in a seaway. It seems likely therefore that if the bulb were to assist in reducing pitching, it would only be useful if it were applied to a hull form which was much more V shaped forward than the Spectrum 42, which does not pitch in any case. It seems that the dramatic difference in pitching claimed by some, as a result of fitting a bulb bow to an existing hull, must be due to the change in hull shape along the forward under body, caused automatically when a bulb is fitted, rather than by any reduction or control on the movement of centre of buoyancy by the bulb.

Relating Reality to Theory

In a mutlihull where, when the boat is sailing, one hull is lifting out of the water and the other is being pushed down into the water, a program like MacSurf and MacHydro give us the opportunity to study the waterlines at various angles of trim, heel and hull sinkage, along with the hydrostatic variations in a way that has never been possible before. We all know that it is not enough to sit behind a computer screen playing with numbers, and hope to produce the ideal boat. Sailing on the boats, in real conditions, is an essential part of the design process. Up until now there has been a wide gap between the drawings of the boat, including the dynamic and hydrostatic analysis, and the actual reality of sailing. The gap has now been dramatically narrowed, because we can emulate and study the hulls in their exact sailing attitudes, directly on the screen. The waterlines can be printed or plotted, and studied at any angle. lt is obvious that is far more relevant for a designer to study his hull shapes in a three-dimensional form, as if they were actually sailing, rather than the conventional view of the hull, with waterline and trim in the position that it would be when the hull is at rest. Although it was possible to draw these shapes before, it was very time consuming and rarely done. And certainly never done in the increments that are now possible. Now, with this extremely fast facility, a hull can be drawn in its actual sailing position, and hydrostatics analysed in a matter of minutes. Fig 3 shows Livery Dole III sailing in a force 6 wind. Note the main hull is just skimming the water. The boat has trimmed up at the bow and the last part of the main hull to leave the ater is the stern area above the rudder.

The actual sailing positions of the hulls of LD II are shown in the computer simulation in Figs 4a and 4b.

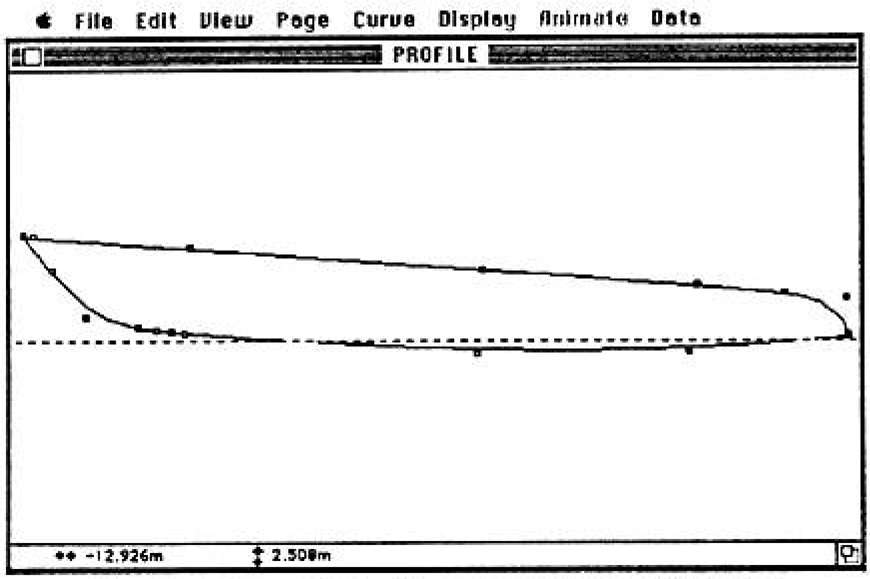


Fig. 4a. *Livery Dole III* main hull in sailing trim from MacSurf.
This shows the computer emulation of the main hull of the same boat, generated by MacSurf.

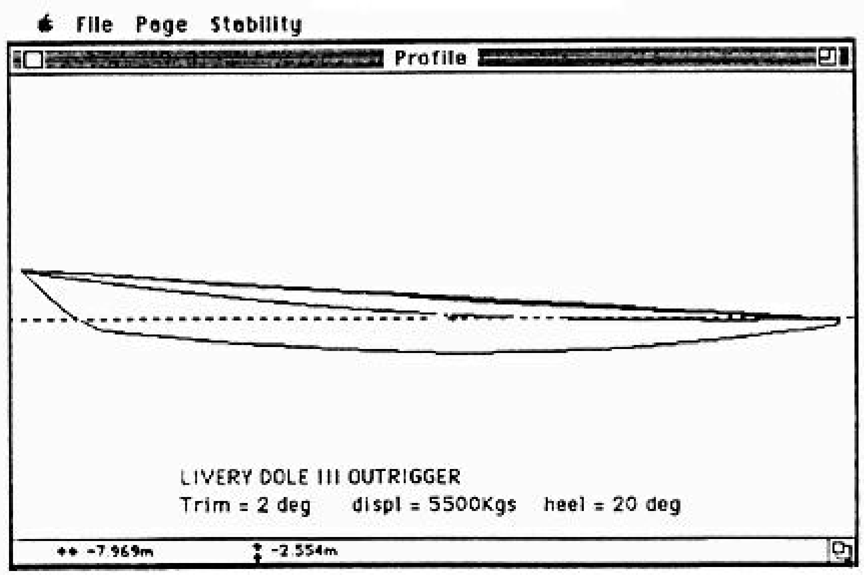
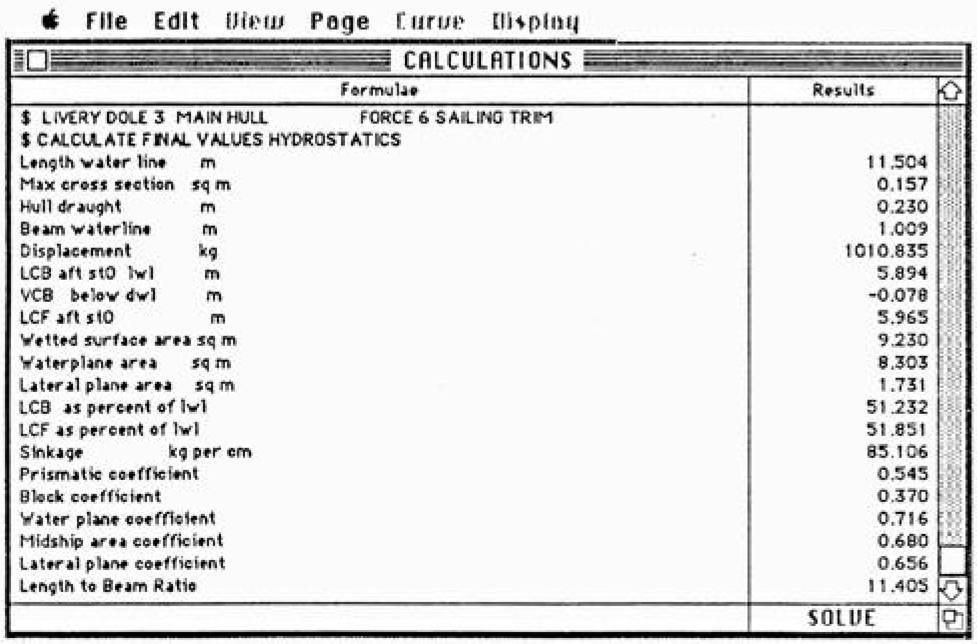


Fig. 4b. *Livery Dole III* outrigger in sailing trim, from MacHydro.
This shows the outrigger, again in it's real sailing attitude.

The hydrostatics of the hull can then be caclulated for each position of the hull in various wind speeds. This is shown in fig 5.



Formulae	Results
$ LIVERY DOLE 3 MAIN HULL FORCE 6 SAILING TRIM	
$ CALCULATE FINAL VALUES HYDROSTATICS	
Length water line m	11.504
Max cross section sq m	0.157
Hull draught m	0.230
Beam waterline m	1.009
Displacement kg	1010.835
LCB aft st0 lwl m	5.894
VCB below dwl m	-0.078
LCF aft st0 m	5.965
Wetted surface area sq m	9.230
Waterplane area sq m	8.303
Lateral plane area sq m	1.731
LCB as percent of lwl	51.232
LCF as percent of lwl	51.851
Sinkage kg per cm	85.106
Prismatic coefficient	0.545
Block coefficient	0.370
Water plane coefficient	0.716
Midship area coefficient	0.680
Lateral plane coefficient	0.656
Length to Beam Ratio	11.405

Fig.5. Calculation page for *Livery Dole III*'s main hull in Force 6.

Movement of the Centre of Buoyancy (C of B) in a multihull.

As a multihull sails in increasing wind strengths, one hull sinks while the other lifts. Threfore the combined hydrostatics of the whole boat to change with angle of heel. One of the most important factors is the way that the C of B moves in relation to the Centre of Gravity (CG). In a Catamaran, when the boat is at rest the C of B has to be directly over the CG. But, when the boat heels the hull can be designed in such a way that the C of B moves forward - so that the boat has a tendency to trim slightly up at the bow, on a reach. With MacHydro, each hull can be progressively immersed or raised in small increments and, in each case, the hull is allowed to trim into its natural position.

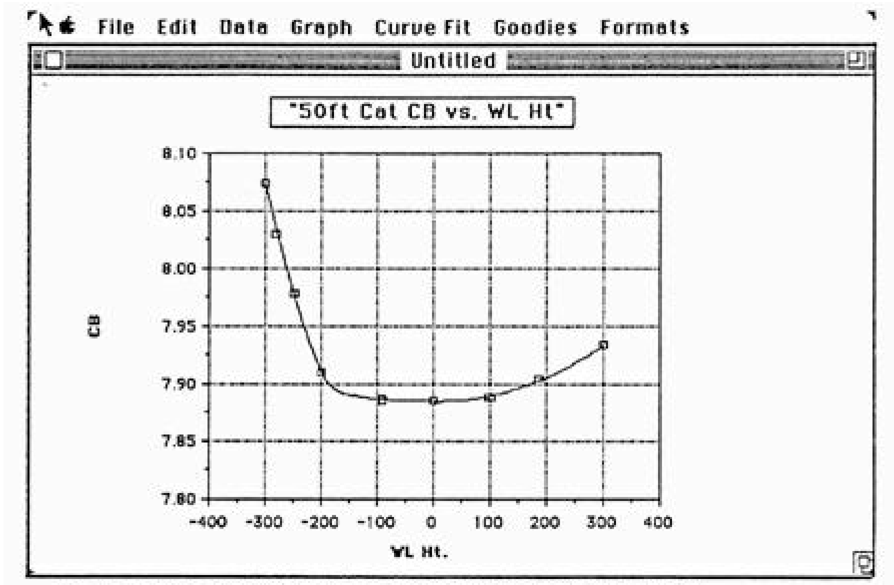


Fig. 6. Movement of Centre of Buoyancy vs. hull immersion for 50ft catamaran

This means that we can obtain a graphical representation of how the C of B moves as shown in Fig 6 and at the same time we can monitor all the other hydrostatic changes.

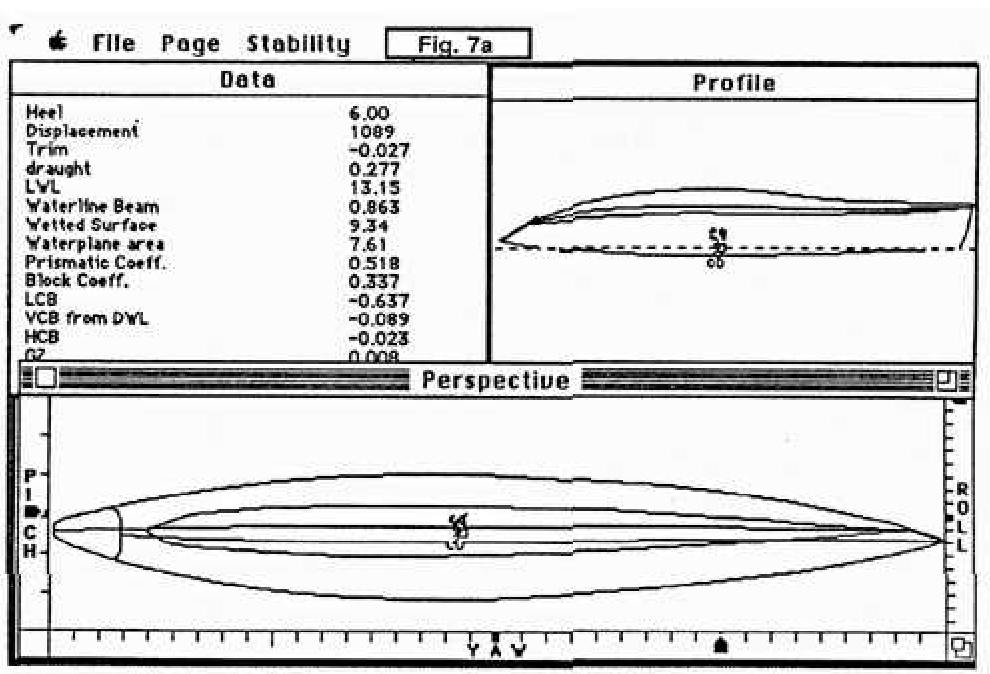


Fig. 7a. 50 ft. catamaran windward hull in Force 5.

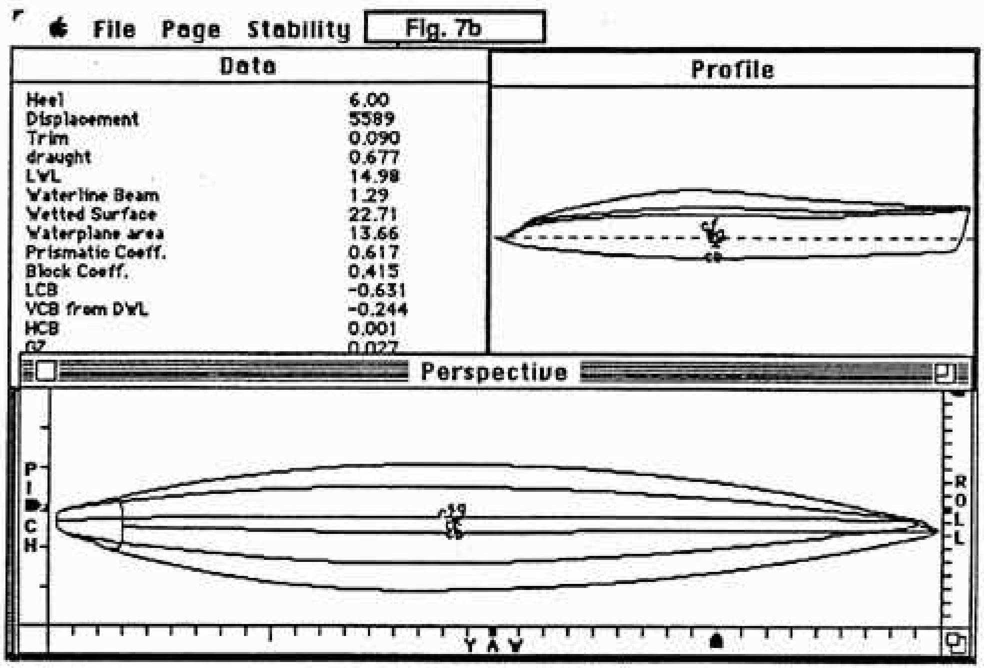


Fig. 7b. 50 ft. catamaran downwind hull in Force 5.

Figs 7a and b show the profile, plan, and data sheet views from MacHydro, of the two hulls of the 50ft cat in their actual sailing position, when reaching in a Force 5 wind. When developing a new design, it is easy to go between MacSurf and MacHydro to create many new hull shapes and compare them in sailing trim and create hull shapes that will sail at safe angles of fore-and-aft trim while still maintaining efficient waterline shapes at any angle of heel.

Curve fitting and hydrodynamic analysis.

As mentioned above, some of the early programs used for designing computer generated hull forms restricted the hull shape that could be obtained. The usual method was to use a mathematical equation to draw the curves. The parameters of the equation being defined by the designer. For instance Hugo Myers developed a cubic equation to draw hull lines. Now, while this produced mathematically fair lines, it did place severe restrictions on the hull shape that could finally be obtained. Nevertheless it could be argued that the equations could possibly have been related to hydrodynamic theory to produce an efficient hull form. Although I find it hard to believe that it would be realistically possible to put this into practice in a 3 D form. With MacSurf the possibilities of relating hull form to hydrodynamic theory are much greater. Fig 8 shows a 4th order polynomial curve fit to the waterline of a 50 ft cat.

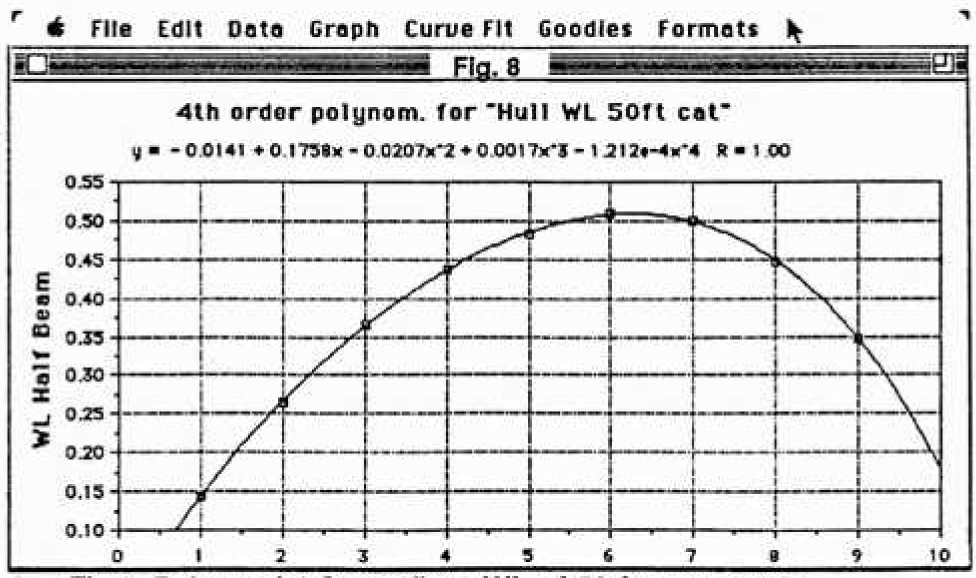


Fig.8. Polynomial Curve fit to WL of 50 ft. catamaran

Curve fitting like this (for higher or lower order polynomials) can be carried out very easily at any waterline, buttock, or diagonal at any angle. This means that water flow can be monitored mathematically along any line on the under body of the hull, at all positions of actual sailing attitude. This is a completely revolutionary concept for a low-cost system. The cost of the system is extremely relevant, because if the system is as cheap and as easy to run as MacSurf, designers will take advantage of n and use it. While it may have been possible to do all the things I have described in the article on a large mainframe computer, very few designers would have the chance to use the program regularly, and development work would probably be restricted to special projects like a 12 meter campaign. The other problem with mainframe computers is that the programs are usually written for programmers and can be difficult to run. The arrival of Micros that are designed to be extremely easy to use has, in fact, greatly increased the CAD potential. Programs like MacSurf that are written in this environment have enormous design potential because they are both so easy to use and fast, that many more people will use them. And the more they are used, the greater will be the effect on yacht designing as a whole.

Conclusion and the Future:

Designing

We are currently carrying out a program of analysis of all existing designs to form a solid database of theory combined with actual sailing experience. This gives us a sound basis for further development work on hull shapes, in order to increase performance, while at the same time improving sea keeping qualities and safety. Our first 2 cats, designed completely on MacSurf, are under construction, and feedback from sailing them will immediately influence any changes to hull shape in the future. I am also in the process of using MacSurf to develop a theory that relates the movement of the Centre of Buoyancy of the hulls to the pitching moment. This theory in relation to our current experience of hulls that do, and do not pitch, will help to ensure that we can carry the benefits of good design to all types of boats whether cruising or racing.

Our future designs will be influenced greatly by the new possibilities of studying the underwater shapes in real sailing attitudes. More accurate analysis of multihull hull forms that will remain fast, but will prevent bow burying on a reach, are now feasible. Thereby making the boats safer and more sea kindly.

MACSURF

One of the most impressive aspects of both the Mac and the MacSurf program is the speed at which all operations can be carried out. There is a definite correlation between the speed and ease of operation and the amount that the computer will be used. Firstly for standard work, and secondly as a tool for development of new ideas. There is no doubt that the speed of MacSurf makes this program an essential tool for any yacht designer who is not only interested in speeding up his design process and providing better, more accurate lines to the builder, bur also as a remarkable tool for the development of new ideas and studies of hull hydrostatics, in a way that has previously not been possible. It is likely that the availability of this type of program, and the new possibilities it opens up, will have an enormous influence on the hull designs for all types of boats in the future. Andy Mason chose the Macintosh be- cause of the excellent screen resolution and inbuilt graphics routine. He was convinced that it would be hard, if not impossible, to find another microcomputer that would be as user friendly and as fast as the Mac. Initially I was not convinced about the Mac but, having used it alongside my other computers, there is no doubt that it is extremely simple and fast to operate and very easy to teach someone else to use, which is an essential factor in buying a new computer or program. MacSurf is financially economical in the time that it saves, and ease of which it can be taught to a new user, partly because the program is very user friendly and also because the Mac is one of the simplest computers to operate. Looking around my design office at all the various aids to design that we use, there is no doubt in my mind that with the constant updating and development of the suite of programs that are coming from Graphic Magic, this is becoming the most revolutionary and significant tool ever to be made available to yacht designers