Ocean Going Multihull Design and Safety Considerations

Hugo Myers, April, 1980

Introduction

The multihull development is now well into its second generation. Structures, sail plans, materials and general configurations have been widely tested, and their advantages and disadvantages are well known. Therefore, this paper will concentrate only on more advanced concepts of hull shapes and safety considerations which are currently at the edge of the state-of-the-art.

Fine Exits vs. Full Sterns

There may be general agreement that the hulls should be long and narrow, but there is wide disagreement about the shape of the sterns. Many designers prefer flat runs and chopped off sterns; others select fine exits of about the same sharpness as the very fine bow entry angles.

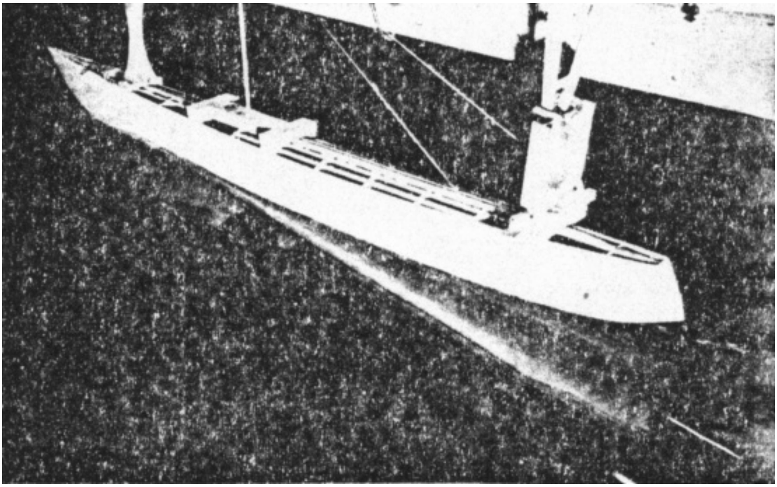


Figure 1. Tank tests of a fine exit hull. (v/sqrt(L) = 3.2, or 20 knots for a 40 foot LWL)

To investigate this question, a fine entry and exit model was built and tank tested at the University of Michigan (Fig. 1). The results were then carefully compared with those of some U.S. Navy high speed, light weight destroyer shapes similar to full stern multihulls. The comparison on an equal displacement and waterline basis are shown in Fig. 2.

Smooth water tank tests are realistic at low speeds, but quite unrealistic

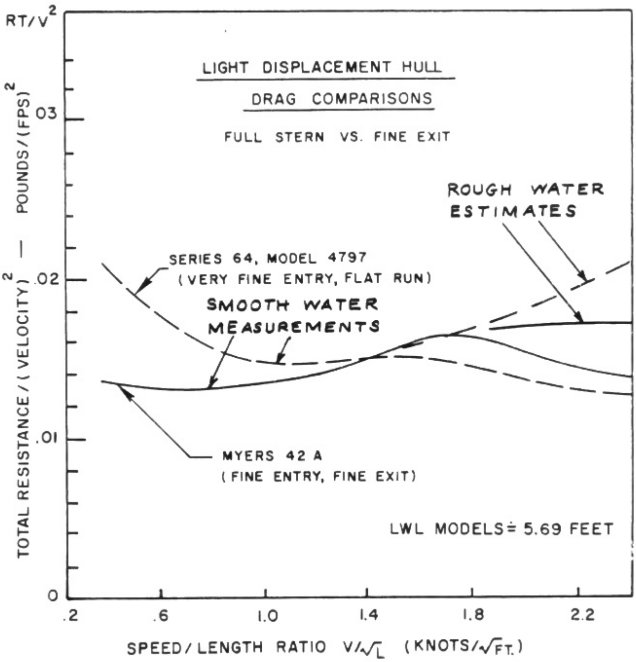


Figure 2. High speed hull comparison at fine exits vs. full sterns.

at speeds above ‘hull speed’, where in the ocean the waves are bigger for the stronger winds and higher boat speeds. From Fig. 2, at very low speeds the turbulence around the stern cause greatly increased drag. At intermediate speeds, before the rough water effects of periodically burying sterns, the drag are similar. At high speeds in rough water the sterns are periodically and frequently buried, and it is estimated that the additional drag due to flat sterns reappears.

Underwater flat stern drag is not a minor effect. In 1974 this drag was not understood by one 12 meter syndicate, and they chopped off the hull underwater to try to beat the rule. It was a million dollar mistake. The yacht lost almost every race it entered.

The physical phenomenon at work is that the water presses in against the hull as it flows past. This pressure is less at the stern than at the bow, but it is still present. The energy expended in pushing the water aside at the bow can be partially recovered toward the stern, because as the hull comes together there is a component of this pressure which is in the forward direction. The effect is like that of squeezing a watermelon seed. If you squeeze hard enough, it will shoot out from between your thumb and finger, due to the slightly forward component of the pressure applied. If the stern sections underwater close too rapidly, or are cut off, this energy is not recovered, but appears as chaotic turbulence. This is the famous “Bone in the Butt”, interesting to photographers and spectators, but about as useful as a “Bone in the Teeth” for winning races.

Fine exits are graceful, but somewhat expensive, because the hulls are longer for the same accommodations and waterline length. Fine exits are not required for the main hull of a trimaran, because the main hull is in effect the windward hull and is lifted somewhat, especially at the higher speeds. Generally, the sterns of catamarans should be flared, or somewhat fuller than the bows, to reduce the pitching amplitude and force the bows down slightly for improved windward performance. As far as accommodations and cost are concerned, when considering ocean race winners and record breakers, the priority of performance over luxurious accommodations and economy must be set straight at the start.

Hull Cross Sections

Semicircular underwater cross sections provide minimum wetted surface for a given displacement and waterline length. However, in ocean racing multihulls, crew weight is not such a significant percentage of total weight as for day sailors, nor is it as manoeuvrable. Crews have to sleep, and extreme crew positions such as on the windward stern or in trapezes are neither useful nor advisable. Therefore, the actual sailing displacement of the leeward hull is much less predictable or controllable. What is required is not merely minimum wetted surface area for a given displacement, but a minimized total (friction + wave + induced + rough water) drag over a maximum variety of conditions.

Three additional factors influence the underwater cross section. At low angles of attack the induced drag of the hull due to lift is quite low for the actual lift generated. In plain terms, the side of the hull is not a bad keel at low leeway angles. Therefore, it is desirable to use it in order to reduce the size of the retractable boards and the attendant structural and accommodation problems.

Secondly, the finer the hull, the lower the wave and rough water drags. At high speeds, these two drags combined are still greater than the friction drag, even for the modern, very light ocean racing multihulls. Third, for both aesthetic and windage reasons it is desirable to keep the freeboard low, yet the crew deeply appreciates full headroom for dressing and getting about. All of these considerations tend to lead toward the requirement for a deeper than purely semicircular hull. Thus, elliptical or parabolic cross sections are frequently used, as shown in Fig. 3.

Mathematical Hull Lines

The advent of high speed computers makes feasible the development of mathematical hull frame offsets and lines. The physical concept is that the mathematics forces the hull into the gentlest possible curvatures (from the simplest equations) which then result in minimum change of momentum of

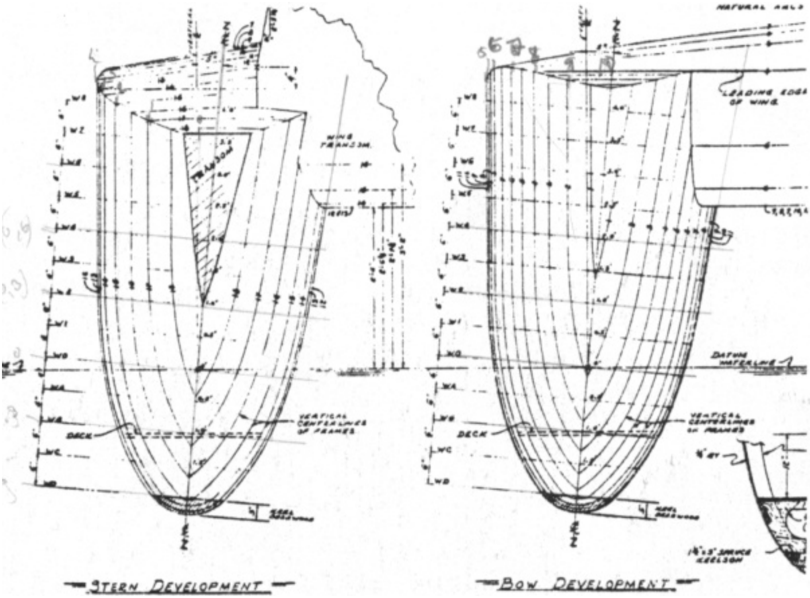


Figure 3. Mathematical lines of a 40 foot catamaran.

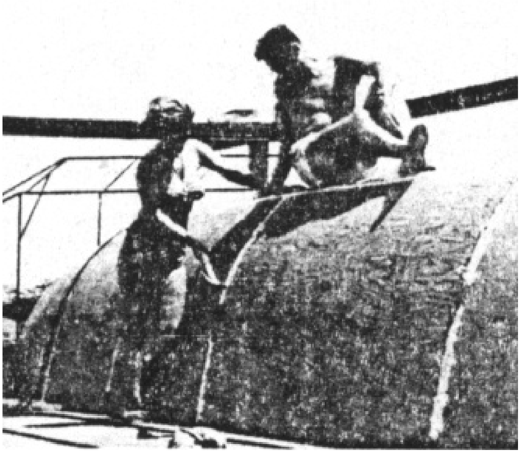
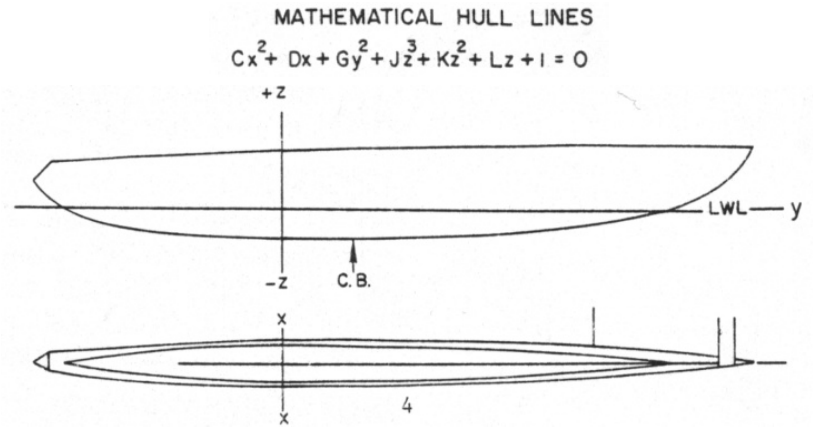


Figure 4. Graceful curves.



the flow (wave drag). Also, once the equations have been developed, parameters are easily varied to find the hull that provides minimized wetted surface area over a wide variety of conditions. Fig. 4 illustrates the utility of graceful shapes, and Fig. 5 presents the frame curves and advantages of the mathematical hull lines approach used by the author in many of his designs.

More complicated shapes can be accommodated by a single equation, as shown in Figures 6 and 7. These surfaces all exhibit gently curved lines and minimization of wetted surface area and change in momentum of the flow.

The 44 foot racing catamaran "Sea Bird" utilizes the symmetrical, fine exit mathematical hulls similar in section to those of Figure 3. She currently holds the Ocean Racing Catamaran Association's Trans-Pacific (Los Angeles to Honolulu) record of 8 days, 18.5 hours. Fig. 8 presents a bird's eye view of her easing along at eight to ten knots. Note the very small stern wake created by these hulls as they slip through the water at a little over the 'hull speed limit'.

In fact "Sea Bird", with her 36 foot Load Water Line (LWL) length, holds an all-time trans-ocean sailing record, when waterline length is considered. That is, she averaged over 11 knots, or over 1.2 times her 'hull speed' in the more than 2200 nautical mile crossing from Los Angeles to Honolulu. Thus "Sea Bird" broke the wave drag barrier for the entire ocean crossing. No other sailboat has ever accomplished this, and it may be a few years before one does significantly exceed this record.

Such records are not established without risk. “Sea Bird”* carried a cloud of sail with an expert crew and good wind conditions.

This brings us to the problem of multihull safety at sea. Before progressing to solutions, it is instructive to consider the dynamics of the combination of wind and wave induced capsizes.

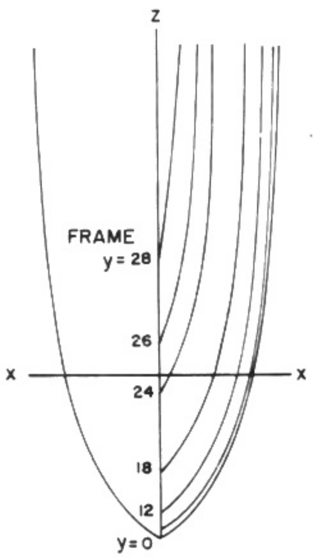


Figure 5. Frame curves and advantages of the mathematical hull lines approach.

Mathematical lines and offsets have been used by shipbuilders and aircraft manufacturers for years to define sections of hulls. They provide a systematic method for classifying hull shapes and insure perfectly fair curves.

Multihulled yachts can have simpler lines than monohulls since not all the functions of leeway resistance, righting moment, and low drag need be combined in one form. The three dimensional limited cubic surface as about the simplest one that can provide an acceptable combination of bow and cross section shapes. By varying only two of the coefficients, the hull can have fore-and-aft and/or cross section asymmetry. The equations represent the complete hull, stem to stern, and shear line to keel.

The offsets obtained by solving the equations at the desired stations lie on gentle, perfectly fair lines. The result is a beautiful hull for which full scale lofting is not required. In addition, the curves are so gentle that single sheet of plywood can be bent around them, eliminating the tedious and expensive laminating process.

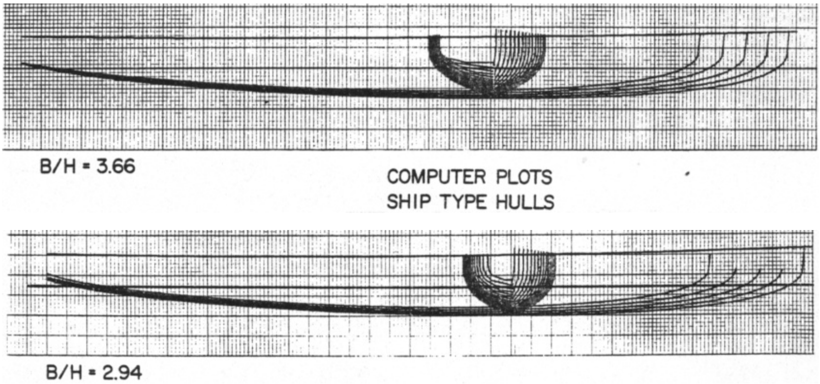


Figure 6. Gentle curves yield minimized wetted surface area and change in momentum of the flow.

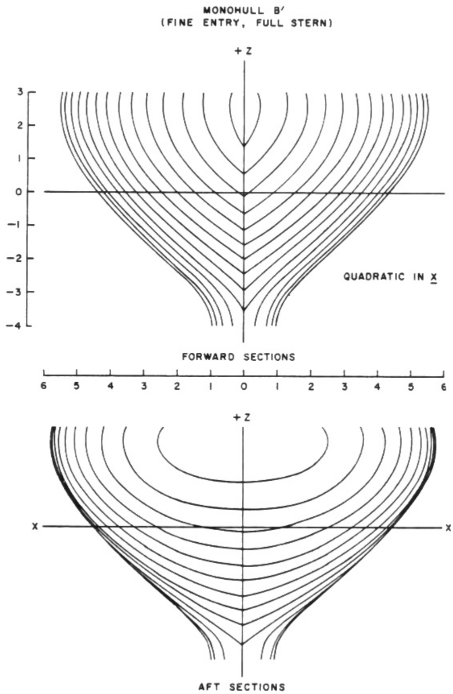


Figure 7. Keel yacht hull shape determined by a cubic equation.

Figure 8. 39' LWL "Sea Bird" averaged 20% over 'hull speed' for the entire 1974 Los Angeles to Honolulu race.

Multihull Capsizing in Wind and Waves

For small multihull racers, sailing in strong winds but relatively smooth protected waters, capsizing is usually due to a wind gust, rather than wave action. The steady state wind speed required to capsize the boat is easy to compute from sail area, mast height, total beam, and boat and crew weight considerations.

Because of its simplicity, this concept has been applied to larger ocean going multihulls. However, as too many trimarans and catamarans have demonstrated, sometimes wave action can be a significant factor in the ocean. Therefore, a more general theory is required which combines the dynamic effects of wind and wave on a catamaran or trimaran.

A technical paper has been written by the author which derives and solves the non-linear differential equation of motion of multihull capsize due to the combination of wind and wave effects. It is not appropriate to go into the mathematics here, but the summary figures from the paper are instructive.

Fig. 9 shows the geometry of a typical catamaran on a wave, and Fig. 10 shows the geometry of a trimaran. The solutions for the roll angle (t) as a function of time are presented in Figures 11, 12, and 13.

Using typical 40 foot LOA, 6500 pound trimaran and catamaran characteristics, solutions for (t) were obtained for three cases: medium wind and 'rogue' wave, strong wind and 'huge' wave, and gale wind and 'large' wave. All the waves are assumed to have a face slope of 30 degrees. The 'rogue' wave lifts the windward hull of a catamaran, or the main hull of a trimaran, 10 feet in one second. The 'huge' wave lifts the hull 7 feet in one second, and the 'large' wave lifts the hull 4 feet in one second.

The trimaran suffers from two fundamental disadvantages. Even under normal press of wind the trimaran heels more than a catamaran. Also, because the leeward ama (outrigger hull) is closer to the main hull than the spacing between the two hulls of a catamaran, the lifting of the main hull causes a greater initial roll (angular rotation) rate in the trimaran than in the

* Bob Hanel was the skipper and owner in the 1974 race.

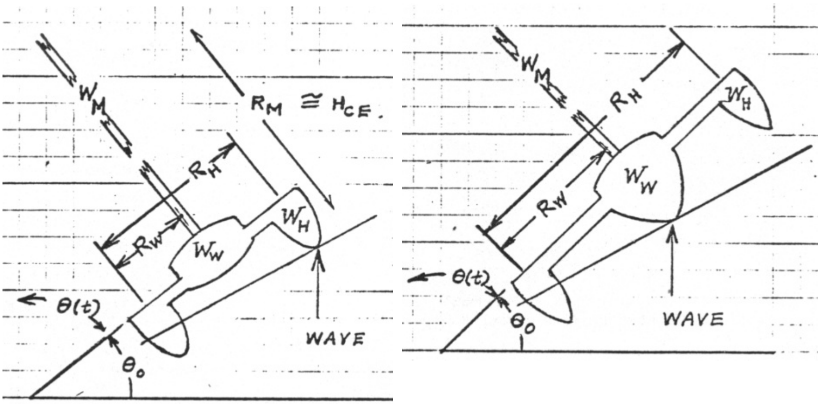


Figure 9. Catamaran capsizing geometry, and Figure 10. Trimaran capsizing geometry.

catamaran. Thus, the initial heeling angle for the trimaran on the steep wave was taken as 45 degrees (15 degrees of boat heel plus 30 degrees wave slope), whereas it was 39 degrees for the catamaran. The roll rates are derived from the rate the main hull lifts about the axis of the leeward hull.

Cases I and II show what happens in huge waves. The larger moment of inertia of the trimaran, which is an advantage when there are no waves, is a disadvantage in waves. The irresistible force of the wave gives the trimaran a greater angular rate, and much greater angular momentum, which is then more difficult for the reduced righting moment at high heel angles to overcome.

Case III is perhaps a more probable situation. Ocean going boats have to expect to be caught in a gale on occasion. In this case the large wing of the cruising trimaran was caught by the gale winds, and the boat went over with great dispatch. When the total wing area (including the windward hulls) was reduced from 520 to 200 square feet, the boat was almost saved. Clearly, it is most desirable to keep the wing area as open as possible.

One way to reduce trimaran capsizing probabilities in waves is to make the boat almost as wide as it is long. Admittedly, this would make for a visually and structurally awkward boat. Otherwise, trimarans should be conser-

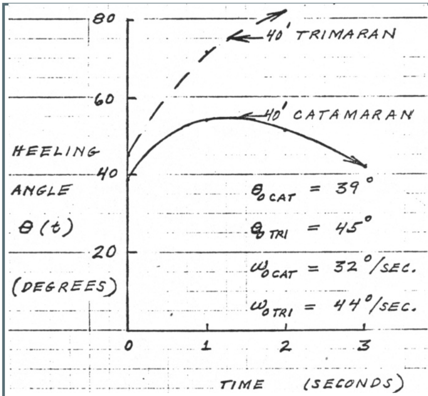


Figure 11. Multihull capsizing: Case I, rogue wave, medium wind.

- Wind speed: 18.7 knots
- Sail area: 800 sqft
- Hull lifted 10 feet in 1 s
- Boat weight: 6500 pounds

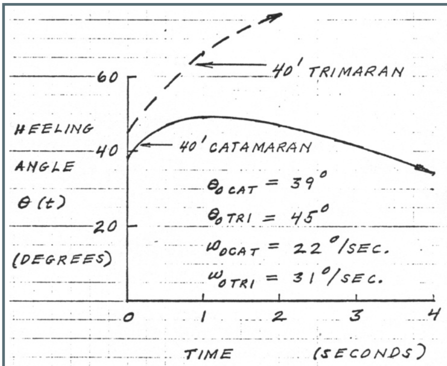


Figure 12. Multihull capsizing: Case I, huge wave, strong wind.

- Wind speed: 37.5 knots
- Sail area: 400 sqft
- Hull lifted 7 feet in 1 s
- Cat beam: 20 ft
- Tri beam: 28 ft

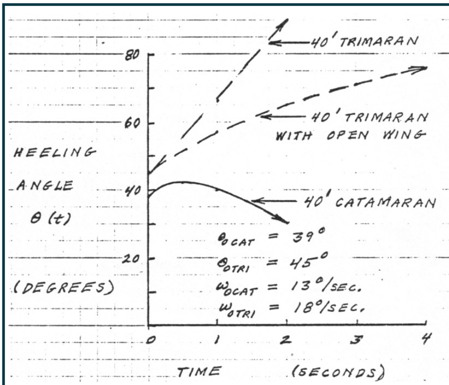


Figure 13. Multihull capsizing: Case II, large wave, gale wind.

- Wind speed: 59 knots
- Sail area: 200 sqft
- Hull lifted 4 feet in 1 s

vatively rigged and sailed, with as little solid wing area as possible, and they should avoid high wave conditions.

On the other hand, prospects for catamaran safety in the open ocean look quite bright. Assuming the boat carries the proper sail area for the wind conditions, even severe waves do not capsize it, because of its initial stability and wide effective beam. After all, a catamaran is just a raft, which is basically a safe platform. With the advent of improved automatic sheet release devices, the probability of catamaran capsizing might be reduced to the order of magnitude of the probability of a keel yacht rolling over completely.

Considering the trimaran problems with waves, and the conventional yacht problems with sinking, properly designed, built, and sailed catamarans could become some of the safest yachts on the ocean. Proper design would take into consideration such problems as the confluence of waves as occur off Cape Hatteras, or in the channels between islands by reinforcing the hulls and wing intersections, and deflecting and venting the mountainous wave energies. Proper sailing includes reefing down early to avoid overloading the yacht and paying great attention to keeping the yacht shipshape and seaworthy.

Capsize Prevention Techniques

1. The Chicken System

The very best capsize prevention device is an experienced and alert crew member on deck, in addition to the helmsman. A manual practise, called the "Chicken System", has worked well for "Sea Bird". Both the helmsman and the crew hold a sheet in their hands if there is any risk of capsizing, as shown in Fig. 14. The rule is that each man has the obligation to release his sheet if he senses any problem. Thus, each one backs up the other, and frequently both sheets are released simultaneously in practise.

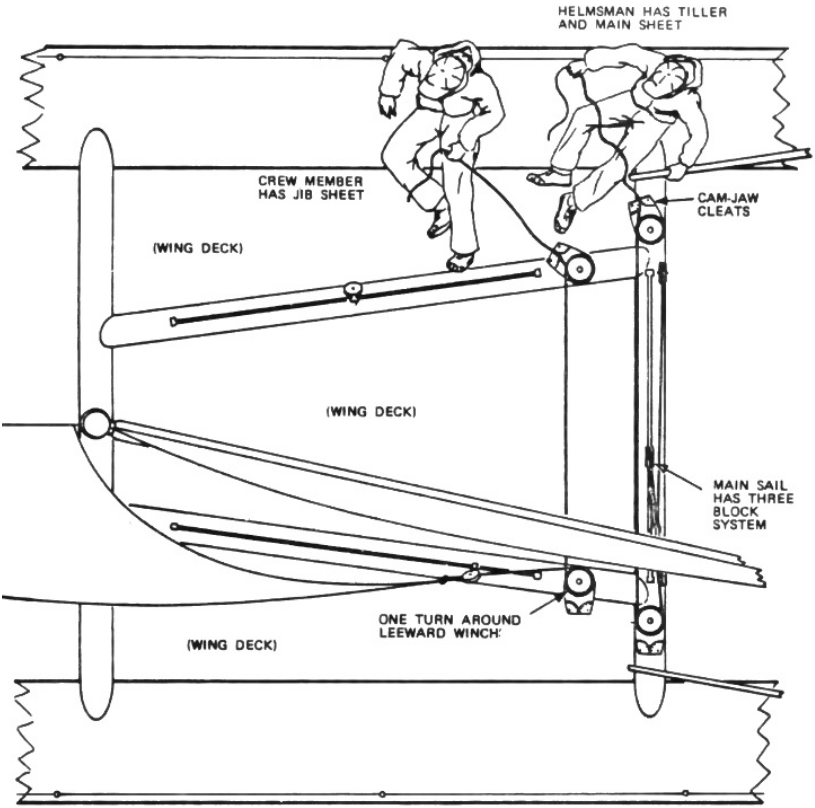


Figure 14. Sea Bird's 'chicken system' to prevent capsizing.

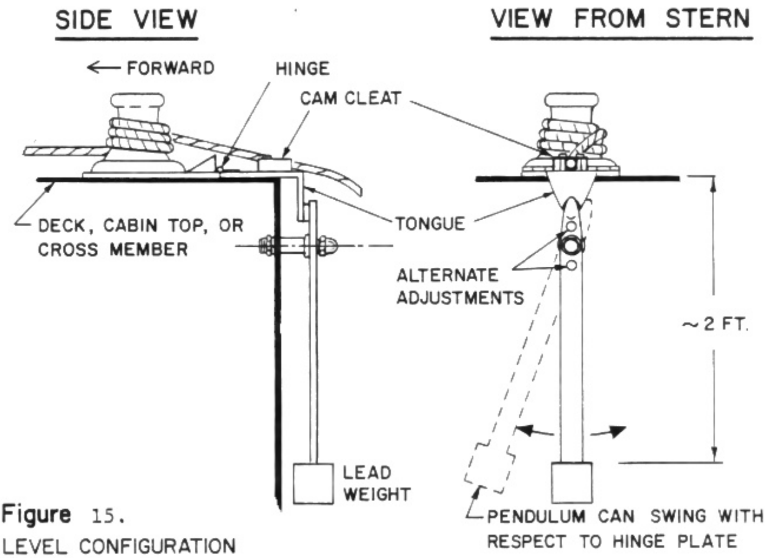


Figure 15.
LEVEL CONFIGURATION

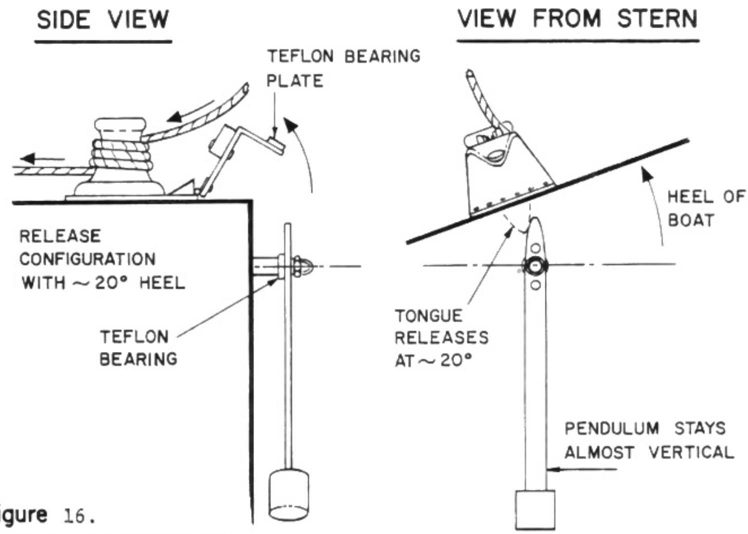


Figure 16.
HEELED CONFIGURATION

Unfortunately, the experienced and alert Chicken tends to be a Deck Ape. He weighs a small fraction of a ton, consumes a lot of food and drink, and is sometimes difficult to manage. Therefore, lighter and less expensive systems are desired.

2. The Pendulum System

Fig. 15 shows the pendulum sheet release system of the type developed for small catamarans by Lars Oudrup. When the boat heels the pendulum swings away from the tongue of the cam cleat base. The cam is then pulled up and forward by the tension on the sheet, and the sheet then easily pulls out the top of the cam, as shown in Fig. 16. The cam cleat is mounted on a horizontal base rather than vertically to eliminate the friction on the line over and edge. The correct number of turns has to be used on the winch so that there is enough tension in the sheet release if the boat heels too far, but not so much as to pull the sheet straight out of the cleat.

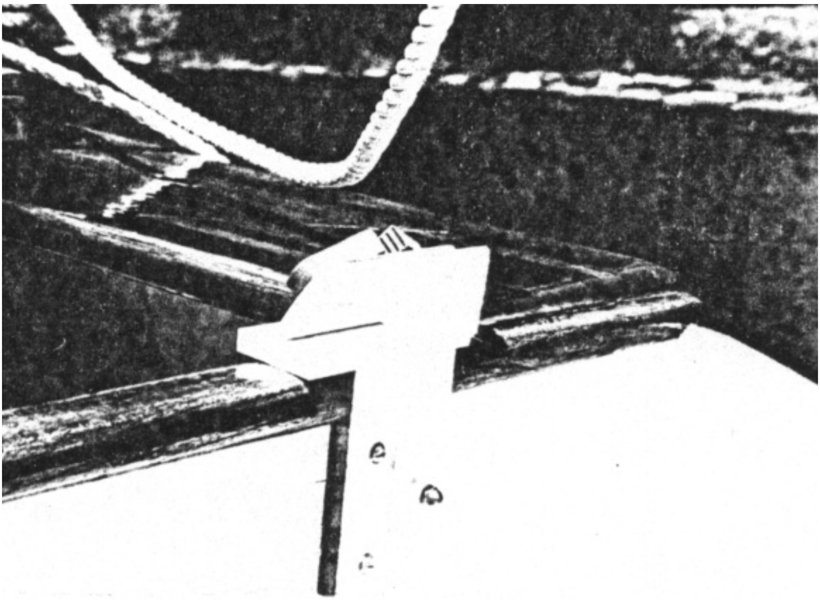


Figure 17. A pendulum system in the release mode.

In his 1976 Observer Single Handed Trans Atlantic Race (OSTAR) David Palmer used the pendulum system. He reported, “The Lars Oudrup sheet release is so simple that when I first saw it I thought there must be a snag. It requires no electronics and relies on nothing more sophisticated than gravity and a hinge. You can set it so that it releases at any angle of heel you like. Its only minor fault is that when the sea is at right angles to the boat it cannot tell the difference between wave-induced and wind-induced heel. It therefore lets go more often than you want. That is a fault in the right direction.” Figs. 17 and 18 show a Myers pendulum in the release mode.

Figure 18. Donna Schmidt demonstrates a pendulum system.

Dynamic damping is a problem with the pendulum system. In rolling situations the pendulum arm tends to overshoot and let go too frequently. Also, it is often hard to find a suitable place on a yacht for a pendulum arm to hang and swing. Finally, many owner simply do not wish to clutter up their yachts with any such devices.

3. The Sailsafe System

In a very good attempt at a more sophisticated automatic sheet release systems John Hepplewhite development an electromagnetic control mechanism based on a mercury switch. At preset angle of heel the switch closes. Dynamic damping does not seem to be so much of a problem, probably due to the high viscosity of the mercury. A solenoid is actuated which completely releases the sheet from the cam.

Multihulls International magazine reported: "We are pleased to see the re-emergence on the market by Saxon Marine in England, now being sold worldwide by G. & M. Power Plant Co. of Ipswich, England, under the name of Sailsafe."

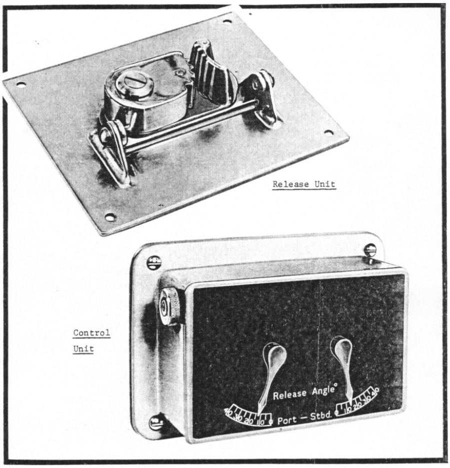
"The new sheet release has been completely redesigned, and reliability is said to be greatly improved. The cam plates and cams are investment cast in bronze and whereas the old unit required a slight upward angle of the sheet, this new release is insensitive to the sheet angle so long as tension in the sheet is limited by three or four turns round a winch. It is emphasized by the makers that it is essential to install the release "after" the winch, i.e., the sheet goes from sail to winch and from winch to the Auto Release cam cleat."

"A control unit with port and starboard rotary release angle setting switches is mounted horizontally and athwartships – usually in the saloon. These rotary switches are to preset the required angle of heel at which the cam cleat will automatically release the sheet. when the preset angle of heel is reached, a mercury switch makes contact and a solenoid under the cam cleat plate unlocks the cleat to give instantaneous release of the sheet."

"The Sailsafe release works on a 12 volt D.C. supply; 24 volt models are available but to special order only. Sales representation is solicited for most countries, but in the U.S.A. sole distribution is in the hands of Myers Catamarans International of Vienna, Virginia* The Sailsafe will be of particular interest to single-handers and to family multihull cruising enthusiasts as it virtually eliminates the fear of inadvertent capsize."

An earlier version of the Marinax Sailsafe automatic sheet release system is shown here.

* 1701 Bronco Lane, Vienna, Virginia 22180. Tel. (703) 938-5909.



Conclusions

Automatic sheet releases have been successfully ocean tested for over a decade. At least two types are now commercially available. It is high time to install them on ocean going multihulls to prevent the loss of lives and yachts at sea.