Multihull Design Considerations for Seaworthiness.

By John Shuttleworth.

This Paper evaluates how a multihull performs in waves with respect to rolling and pitching. Stability is evaluated both in relation to wind and wave action. In particular reference will be made to Prof. Marchaj's recent work - 'Seaworthiness the Forgotten Factor.' Multihulls are studied under the same criteria as monohulls are evaluated in the book, giving a clear comparison between old and new multihull designs, and monohulls, particularly with regard to capsise in wind and waves. Other factors affecting seaworthiness, such as pitching, surfing, rolling, yawing etc, are discussed.

A vector analysis of the lift to drag forces acting on a multihull is presented, and each factor such as hull drag, windage, keel and rig efficiency, etc, are directly related to pointing ability. These factors are related to several multihull types, and it is clearly demonstrated why old multihulls did not point well to windward, and why modern ones do. A method for calculating the wind speed at which a yacht will stop sailing to windward is presented, and related to real designs, with a discussion on how to improve windward ability in a gale, and hence improve seaworthiness. A brief discussion on modern construction techniques to reduce fatigue, high stress concentrations, and the effect of collision damage is presented, with a note on how computer aided design can be used to improve the aerodynamics of the boat above the water.

Seaworthiness - basic concepts

The seaworthiness of a vessel, in broad terms, is the ability of the vessel to provide safety, and comfort for her crew in all weather conditions. The concept of seaworthiness should not only be considered in storm survival conditions, because vessels can be lost in moderate conditions as well as in storms. The effects of fatigue in construction materials and rigging could result in failure in moderate winds, and crew fatigue due to extreme motion could result in errors of judgment, or exhaustion, long before a dangerous situation need otherwise have developed. Collision for instance can occur at any time, and accounts for the loss of a significant number of yachts, and in my opinion is a bigger danger than a storm.

In this paper I shall explain some of the many factors that affect the seaworthiness of multihulls. Including windward ability, stability, motion in waves, and pitching and rolling. I will explain how the construction can be designed to reduce stress concentrations, and how fatigue of materials is taken into account. I will indicate how different multihulls can be made safe in the event of a collision at sea. Along the way I will show how computer aided design can assist in designing hull shapes to control pitching and prevent bow burying characteristics, and to improve aerodynamic streamlining.

The most informative work on seaworthiness in modern yachts to date is Seaworthiness the Forgotten Factor by C.A. Marchaj. Unfortunately the book concentrates almost exclusively on monohull design and very little is mentioned about multihulls. Since space is limited, I will not redefine the formulae and criteria for seaworthiness, which are explained
clearly in the book, instead I will just go straight on to show how a multihull fits into the picture. On reading through Seaworthiness the Forgotten Factor, I could not help constantly thinking how few of the vices and problems attributed to monohulls were applicable to modern multihulls.

Over the past 20 years a number of distinct types of multihull have emerged all having different sailing qualities, and seaworthiness. There has been a steady improvement in the understanding of the factors required to make a multihull both safe and fast, resulting in boats that are extremely seaworthy, as will be demonstrated by the following analysis.

The basic types of Multihull are as follows. Obviously these are the extremes, and many boats will fall between the categories. The groupings given here represent a chronological order in only a very general way. Boats having some of the characteristics of the most modern types can be found in multihulls whose designs date back over 1000 years. On the other hand boats of all types are still being designed and built. From a subjective point of view, the order given here follows my own multihull sailing and design experience closely. I first sailed across the Atlantic some 17 years ago in type 1, later I crossed again in a type 2, and a few years ago in a type 3. Recently most of my long distance ocean voyaging has been aboard a type 6 catamaran. So the "generations" are more applicable to my own rather than general criteria, even though most observers of the development of the modern multihull will agree with the broad outline of each type.

A keel in the sense used below is a foil for resisting leeway. The keel is not balasted as in a monohull, and may be fixed, or retractable either vertically (daggerboard) or by pivoting (centerboard). Amas are the outer hulls of a trimaran, sometimes referred to as outriggers, or the smaller hull of a proa.

1. Older type of trimaran. Relatively heavy. High Windage. Inefficient underwater and keel shape, often with either a fixed keel or no keel at all. Small sail area. Hard chine with high wetted surface. Poor pitching control. Medium buoyancy amas (around 110% of the displacement of the boat). Amas usually both in the water at the same time. Narrow beam (length to beam ratio = 2). Construction sometimes doubtful often in sheet plywood. Low long term fatigue.


3. Third generation trimaran. Light weight (due to the use of composite materials). Large Sail areas. Wide beam (L/B < 1.5 to as low as 1.0 in smaller boats). High buoyancy amas (up to 200% of displacement). Pitching very well controlled by use of different hull shapes on main hull and ama. Sailing attitude well controlled on all points of sail. Low windage. Dramatic improvement in structures due to use of Computer aided design, and better understanding of composite materials.

4. Early catamaran. Relatively heavy. Narrow beam (L/B often over 2). High windage. Small sail area. Inefficient underwater shape and low aspect fixed keels. Cruising cats very heavy by today's standards. Large flat windows in coachroof causing high windage. Often
prone to hobbyhorsing and pitching due to rocker and symmetry of hulls.


7. Fourth Generation cats. Basically as 6 above but with very streamlined bridgedeck cabin for large accommodation and low windage. Light weight maintained, with large weight carrying ability for fast cruising.

8. Other types. Proas (Atlantic, ama to leeward, and Pacific, ama to windward) and trimaran foilers. In general these are development types almost exclusively for racing, as far as modern multihulls are concerned, and they have special problems that require particular knowledge, experience and seamanship for safety at sea. Due to lack of space these types will not be dealt with in any detail in this article.

Although I am concentrating primarily on cruising designs, most of the design concepts have been derived from successful racing designs. Indeed the racing designs which push the limits of performance to the edge, are an excellent test bed for cruising boats, particularly racers designed for the long offshore events like the OSTAR and the 2STAR, which are both predominantly to windward across the North Atlantic. In these races, ease of handling and motion, windward ability, structural integrity, and seaworthiness are of paramount importance.

It is interesting to note that this development, resulting in a dramatic increase in seaworthiness and speed, has taken place over virtually the same time period as the monohulls have been deteriorating in seaworthiness. The primary reason for this has to be the fact that the development of multihulls has taken place without the restriction of any rating rules, with the only criteria for successful design being to improve seakeeping qualities and overall performance - resulting in the development of extremely seaworthy cruising designs.

**Boat Motion in a Seaway, and the effect on the ships crew.**

There are 6 basic forms of motion in a seaway ([ref 1](#)), which combine in various ways to give the full dynamic movement of the yacht at sea.
1. Rolling.

With the exception of type 2 above, multihulls are virtually immune to rolling. This means that the boat sits on the water like a raft - following the surface of the sea, giving great crew comfort while sailing, particularly downwind. When lying ahull, cats and tris exhibit different characteristics. Firstly catamarans have a very high roll moment of inertia (Ir), because the weight of the boat is primarily concentrated at the hull centerlines. The buoyancy of the boat is also concentrated at the extremity of the hull centerline beam, giving massive roll damping. Open bridgedeck cruising cats benefit most from the effect, and low buoyancy ama trimarans (Type 2) least. In a tri the weight is concentrated closer to the center of gravity (CG), reducing Ir, and the amas take longer to pick up buoyancy as the boat heels, thereby reducing damping. In a low buoyancy ama tri this effect can lead to capsizing in waves, (when lying ahull) as will be shown later, and different techniques of seamanship are required to ensure the safety of this type of multihull in a storm.

2. Pitching and hobbyhorsing.

Many early multihulls were prone to hobbyhorsing, and pitching. This was caused by too much rocker on the hull profile, and fine V sections both fore and aft. As hull shapes improved tending towards more U shaped underbodies particularly aft, pitching still remained a problem, because the large width of the stern sections caused the sea to lift the sterns as the boat passed over the wave, driving the bow down. However we now know that pitching can be dramatically reduced by finer sections at the stern combined with the center of buoyancy being moved forward in the immersed hull, and aft in the lifting hull (ref 2 and 3). This effect can be achieved in both cats and tris, giving a very comfortable and easy motion upwind. At the same time windward performance is improved, because the apparent wind direction is more stable across the sails.

3 Yawing.

Any tendency to yaw has been virtually eliminated in the modern multihull due to the shallow draft of the hull (because of the U shaped sections and the lightweight), and by the use of retractable daggerboards. Once the keel is removed when sailing downwind, there is virtually no chance of broaching, as long as the forefoot does not dig in. This can be prevented by firstly reducing the forefoot, and by picking up buoyancy quickly in the forward sections of the boat above the waterline. Computer simulations of the hull in different bow down trims, and at varying waterline positions, are now an essential part of the design process to control sailing attitude properly, both on and off the wind. see Fig 1. (ref 4).

4. Surfing.

A Multihull will surf very easily, making for fast passage making in the open ocean. Sailing downwind in winds up to 40 knots is usually quite comfortable and easy. The apparent wind being reduced by the high boat speed. However particular attention has to be paid to rudder size and design to maintain good control at surfing speeds in excess of 20 knots. Elliptical balanced spade rudders of airfoil section reduce helm loads and drag at high speeds. Rudder stocks have to be very strong to be able to steer consistently at such high speeds.
speed. I favour using stainless steel or titanium, rather than carbon for rudder stocks, because at least the rudder will bend if overloaded, instead of shearing off. I design for a factor of safety of 1.5 with rudder at 90 degrees to the waterflow at 25 knots. This situation is quite possible if the boat starts to broach and slew down a wave, and the helm is turned to full lock (35 degrees).

Once the wind speed becomes so strong that surfing downwind is dangerous, and if the boat will not make progress to windward or lie ahull, (this could well be the case for types 1, 2, and 4) it will be essential to deploy a sea anchor to control the boat speed. Much has been written on this subject, and certainly is an accepted way of surviving a severe storm in a multihull. From the designer’s point of view it is essential to provide adequately strong attachment points on the bows and sterns.

5. Swaying.

A modern light displacement multihull lying sideways to the seas with no sails up (i.e. lying ahull), and with the daggerboards up, will surf sideways very easily in a breaking crest. It will be demonstrated later that this is a very important feature in the seaworthiness of multihulls lying ahull in a storm. Earlier multihulls with fixed keels and tris of type 2, are prone to tripping over their keels or amas when struck by a breaking crest. Narrow beam increases the danger of capsize in this situation. If sideways motion of
the yacht needs to be stopped, for instance because of a danger to leeward, this can be done by either deploying a sea anchor abeam, or by putting down the upwind board (this only applies to a cat). The upwind board can act as a brake without imparting rotational momentum to the boat. If the boat does not rotate - it will not capsize.

6. Heaving.

This is a complex problem to define clearly for a multihull, because the two immersed hulls are at different places on the wave front at any given time. Nevertheless, they heave less than monohulls because the hulls are slimmer, allowing the boats to cut through the water when sailing. Loss of apparent displacement at the wave crest and rotational momentum imparted to the boat by heaving on the upwind hull will assist in capsizing an overcanvassed multihull due to wind and wave action. Heaving assisted capsize has been experienced particularly in tris of type 2, and cats of type 4. This is of particular importance and will be dealt with more fully in the next section.

Stability.

This is generally a very contentious and little understood subject when multihull seaworthiness is discussed, and is probably the biggest fear that inexperienced sailors have about this type of vessel. And while it is true that certain multihulls have capsized, it is clear from the above that there are many different types of multihull, and indeed there are different ways in which they can capsize. I will endeavour to show that by careful analysis, and a with a real understanding of the factors that contribute to capsize vulnerability, it is possible to design a multihull that is extremely difficult to capsize, and one that is very safe in all conditions. (Bearing in mind that there may be a wave out there that will overwhelm any vessel).

Stability in wind.

Static stability is a measure of the stability of the boat in flat water, and is given by the following formula. (ref 2 )

\[
SF = 9.48 \sqrt{\left(\frac{0.5 \times B \times d}{S \times A \times CE}\right)}
\]

- Where :
  - \( D \) = displacement (lbs).
  - \( CE \) = height of the center of effort above the center of gravity (C.G.) in feet.
  - \( SF \) = windspeed in MPH that the boat has to reduce sail.
  - \( SA \) = sail area in square feet.
  - \( B \) = beam between the centers of the outer hulls in feet.

This formula gives designers a measure of stability as an indication of the power to carry
sail. i.e. the ability of the boat to resist capsize by wind action alone. There are two factors that can reduce SF. Firstly if the boat has a high angle of heel at the point of maximum stability, (worst in trimarans of type 2, and minimal in all catamarans) the correct SF is given by replacing beam in 1 with beam overall x cos(angle of heel). Typical values for SF can vary between 12 mph for a Formula 40 racing catamaran, to over 40 mph for cruising multihulls. Modern light cruiser racers would be in the range of 24 to 30 mph. So it is clear that in addition to the different types of multihull listed above the initial static stability can vary enormously.

**Stability curve and stability in waves**

Righting moment is the distance from the center of buoyancy to the center of gravity x the apparent weight of the vessel. This is basically the vessel's inbuilt static resistance to heeling. The forces that heel the boat could come from the wind or the waves.

![Graph showing righting moment curve for 35ft Cat. and Tri.](image)

Fig. 2. Righting moment curve for 35ft Cat. and Tri.

Fig 2. shows the curve of righting moment versus angle of heel for a typical modern 35ft catamaran and trimaran racer cruiser to my design. The trimaran (Type 3 high buoyancy amas) has an overall beam of 32 ft. and the cat (type 6) beam = 23ft. The trimaran has
less accommodation, and is lighter than the cat, but because of the wider beam it has
greater maximum stability. It is important to note that the max stability of the tri occurs at
around 20 degrees angle of heel, while the cat has a max at about 6 degrees. If the
buoyancy of the ama is reduced below 100% of the weight of the boat (as in type 2
above), the maximum stability will be reduced not only in proportion to the reduction in
buoyancy in the ama, but also by the effect of added apparent displacement from the
downward pressure from the sails at high angles of heel. At 20 degrees this would cause a
loss of righting moment in the order of 20%. If the ama buoyancy was only 80% in the
first place, the total righting moment would be only 60% of an equivalent trimaran of type
3.

![Graph showing righting moment curves for different types of vessel.](image)

**Fig. 3.** Static stability curves give the energy required to capsize
a modern monohull and a modern multihull.

Fig 3 shows the same righting moment curve for the cat versus a typical modern
criuser/racer monohull. The energy required to be input into the yacht in order to roll it
from 0 degrees to the point of capsise (90 degrees in the cat and 135 degrees in the
Mono) is given by the area under the curve. From the graph it is clear that the energy
required to roll the cat over is 50% higher than the monohull. Of course in either case the
initial angle of heel will reduce the available reserve of stability, and in the trimarans this
reduction in energy resistance to roll will be greater than a cat. The energy to roll a tri to
90 degrees is much greater than a cat provided it is of type 1 or 3.
However in all cases, in order to a capsise to occur, the energy from the wind and the waves (equal the area under the righting moment curve) has to be transferred to the vessel in the form of rotational energy. In waves alone, if the energy of the wave impact is not changed into rolling energy the boat can not capsise.

The following table gives the displacement and dimensions of the cat, tri, and monohull shown in the graphs.

<table>
<thead>
<tr>
<th></th>
<th>Catamaran</th>
<th>Trimaran</th>
<th>Monohull</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOA (feet)</td>
<td>35</td>
<td>35</td>
<td>33</td>
</tr>
<tr>
<td>Beam overall BOA (feet)</td>
<td>23</td>
<td>32</td>
<td>10.8</td>
</tr>
<tr>
<td>B = beam betw. centerlines</td>
<td>17</td>
<td>29</td>
<td>N/A</td>
</tr>
<tr>
<td>D = displacement (lbs)</td>
<td>6700</td>
<td>5600</td>
<td>10080</td>
</tr>
</tbody>
</table>

Firstly if we consider the action of the waves alone. Tank testing has shown (ref 1) that capsise due to the action of unbroken waves is impossible. Therefore when a vessel is lying ahull the impact of the breaking crest is the primary means of energy entering the system which may be transformed into roll energy. A multihull follows the slope of the wave face exactly like a raft as shown in fig. 4. However, because the buoyancy and the weight of the vessel is concentrated at the extremities of the beam (particularly in cats of type 6,) multihulls will be more stable against rolling than a simple raft. Equation 2 gives the impact energy transferred to the boat by the wave.
The above equations give us the means to compare the way the two boats change this vitally important impact energy to rolling energy. These equations are in fact very difficult to calculate in reality, but they do tell us that in order to reduce the rotational energy imparted to the boat by a breaking crest, we need to increase \( I_r \) and \( I_a \) and decrease \( r \) and hence \( M_i \).

In a multihull with the boards retracted the lever arm \( r \) is reduced to the distance between the center of lateral resistance (CLR) of the downwind hull and the center of impact on the windward hull side. Obviously this is very small compared to the lever when the keel is down, and hence the impact moment transferred to the boat is very small.

Secondly, particularly in the case of the open bridgedeck cruising cat (type 6), the roll moment of inertia is very high because of the hull configuration. Also \( I_a \) is high since the water entrained by the hull is a great distance from the center of gravity. Therefore this type of cat has the least energy transferred from the wave impact into rolling energy. On the other hand a trimaran with the board up will still have a small \( r \) and hence a low \( M_i \), but the roll moment of inertia \( I_r \) is much lower than a cat, because the weight is concentrated closer to the center of gravity. Therefore more roll energy will enter the trimaran lying ahull than the cat. (ref 17)

So the above equations show that in most multihulls, the energy of impact is not transferred into rolling, and in fact virtually all the energy is absorbed by surfing sideways. This is exactly the same effect that saves the older type of monohull from capsising in waves, the only difference is that the monohull has to experience a knockdown before the keel is almost parallel to the surface of the water, thereby reducing the lever arm \( r \) and allowing the energy to be dissipated into sideways motion.
The multihull that fares worst in this situation is the trimaran with low buoyancy amas. When a wave hits the side of the boat, firstly it will roll quicker and much more than a cat, and if the ama immerses to the point where it digs in, thereby stopping sideways movement, all the energy will be transferred into rolling and a capsise is possible. Also having fixed keels or leaving the downwind board down will greatly increase the risk of capsise in waves for all types of multihull.

Of course the situation may arise when it may be necessary to limit the sideways drift of the boat, for instance if there is a danger to leeward. In a cat this can be achieved safely by lowering the windward daggerboard. All other types will have to use a sea anchor. Whether to deploy the sea anchor from the bow or the side of the vessel depends on the type of boat, and the conditions. Several people have written on the subject including the Cassanovas, and Dick Newick, who both have used and favour this method of controlling drift and rolling in a storm.

**Wind and wave action**

When you combine the action of wind and waves, a catamaran is more vulnerable than a tri, because when a boat is sailing the heaving action of the wave on the windward hull imparts rolling momentum to the boat, reducing the energy reserve left under the righting moment graph in fig 2. If the boat has a low static stability, and is being sailed close to the limit, with the daggerboard down, it will be possible to capsise in waves in a wind speed that would be safe in flat water. Cats are more vulnerable than tris because in general the static stability of the cat is less than an equivalent tri. This is the main reason that tris are considered to be safer for short handed racing - they can be sailed harder in waves with a greater margin of safety. On the other hand this is a very good reason to make cats as wide as possible to increase the static stability and thereby increase the safe sail carrying power.

**Windward ability**

Another area of traditionally poor performance in multihulls is their windward ability. And indeed it is true that the older types of multihull (types 1 and 4) would tack through 100 degrees or more, and had very inferior pointing ability when compared to their monohull counterparts.

Windward ability is a very important measure of seaworthiness, and can prove vital if there is a danger to leeward in a gale. So apart from the need to improve performance for racing, it is essential to design multihulls with greatly enhanced windward ability. It is not enough just to be able to sail fast on a reach.

To understand why the modern multihull is so good to windward, we have to look at the diagram of the forces acting on a yacht when it is sailing in a balanced steady state. See fig 5. ([ref 5](#))
FT = the total aerodynamic force, and RT = total resultant hydrodynamic force. The boat is said to be balanced when FT = RT. It can easily be shown from this diagram that

\[ EA + EH = (\beta) \] ......................................4

and where:

\[
\text{Lift} = 0.00119 \times CL \times VA^2 \times SA
\]

\[
\text{Drag} = 0.00119 \times DA \times VA^2 \times SA
\]

\[
\text{Side Force} = 0.997 \times CS \times VB^2 \times A
\]
Where....

- EA = aerodynamic drag angle
- EH = hydrodynamic drag angle
- CL = coefficient of lift of the sails
- Cd = coefficient of drag of the sails
- VA = apparent wind speed
- SA = sail area
- CS = sideforce coefficient
- Vb = boat speed
- A = area of keel

The diagram and the equations simply tell us that if we can improve the lift to drag ratio of the rig, and of the keel, we will improve pointing ability. But what is really significant is that we can calculate exactly how much we can improve pointing ability by improving lift to drag.

**Firstly the rig and the aerodynamic drag**

The polar diagram of a typical sloop rig is shown superimposed on the yacht in fig 6 (ref 6 & 7). The solid line represents the lift to drag of the sails only, and the dotted line is the lift to drag when the parasitic drag of the windage of the hull is taken into account. In a multihull aerodynamic drag of the hulls is very high, and the following equations allow us to calculate the total drag of the sails and the hulls. (ref 5.)
Cdp = CP x AP / SA ................8

CdTOT = Cdp + Cd ................9

- Cdp = coefficient of drag of parasitic element related to sail area
- Cp = parasitic drag coefficient of each element
- Ap = area of parasitic element
- CdTOT = total coefficient of aerodynamic drag for whole boat + rig

The important facts to note from equations 8 and 9, are that the coefficient of parasitic drag (Cdp) is inversely proportional to sail area. In practice this means that if sail area is reduced, the effect of parasitic drag is increased, thereby increasing the aerodynamic drag angle and reducing pointing ability. Also if windage is increased the pointing ability is reduced. In practice an open bridgedeck cat of type 6 might have CdTOT = 0.33, while
the addition of a bridgedeck cabin with flat sides would increase Cdp by 35%. This will give a CdTOT (including bridgedeck cabin) = 0.39.

If this increase is laid out on the polar diagram shown in fig 6, it will show an increase in EA of 3 degrees. This means that the boat will tack through 6 degrees more. If the Cp of the bridgedeck could be reduced from 1.2 (coefficient of a flat plate) to 0.3 by careful aerodynamic design, Cdp would only be increased by 8.7% resulting in a loss in tacking angle of only 1 degree. Therefore it is vitally important to pay very careful attention to parasitic drag, and to design clean aerodynamic shapes.

To stop a boat making any progress to windward the aerodynamic drag angle has to increase to around 60 degrees, and if the effect of the the waves knocking the boat to leeward is included, this could drop to say 55 degrees. In order for this to happen the total lift to drag ratio has to fall to 0.700. This is quite possible in slab sided bridgedeck saloon cat with a total coefficient of drag (Cdtot) of 0.392. In fact this will occur in such a multihull when the sail area is reduced to 27% of the full working sail plan. When you consider that the usual proportion of the storm jib and deep reefed mainsail is around 20% of the full working sail plan, it is obvious that serious consideration has to be given to boat aerodynamics, not only for good sailing performance, but for basic seaworthiness.

Worse still is that in an older type of multihull where the best tacking angle was only 100 degrees in the first place, (which implies an aerodynamic drag angle of 28 to 30 degrees), the sail area only has to be reduced to 36% before all windward ability is lost. And indeed this has proved to be the case in many of the old designs.

**Computer Aided Design**

We now have the ability to design a hull and decks for a complete multihull directly on a computer screen (ref 4). The computer allows us to rotate the hull and draw sections at any angle across the boat. We can therefore see the shapes that the wind is going to flow over in the exact direction that the wind strikes the boat. Remember that the wind never comes from dead ahead in a sailing boat. In fact the boat is really moving crabwise through the air, at best the wind crosses the boat at and angle of around 30 degrees from the bow.
Fig. 7 shows the perspective view on the computer screen of a bridgedeck cabin for a 43ft cat. It will be obvious that this is a very useful aid in achieving aerodynamically clean 3 dimensional shapes like this. And the next step will be to test the complete hull and bridgedeck in a wind tunnel. However it will also be possible to compare the pointing ability of the real boat that this is designed for, against that of an open bridgedeck boat of the same size. The coefficient of drag can then be calculated from the loss in pointing ability.

**Hydrodynamic Drag.**

If we apply the same treatment to the underwater shape and keel of a multihull by superimposing the results of tank testing on the boat, in the same way as we did for the sails in Fig 6, we find that the effect of drag of the keel and the hulls on the pointing ability is as follows:

- 25% decrease in keel efficiency = total loss in tacking angle of 5 degrees.
- Double hull weight = total loss in tacking angle of 6 degrees.
- if we include the lift to drag factors of the sails:
  - 16% decrease in sail area = total loss in tacking angle of 4 degrees.
  - 35% increase in aerodynamic parasitic drag = total loss in tacking angle of 6 degrees.

The total of all these factors is a loss in tacking angle of 21 degrees.

If we compare an open bridgedeck cat of type 6 to an older type of multihull, this is exactly the sort of difference in pointing ability we observe. When compared to a design of type 1 or 4 the modern multihull is much more streamlined, about half the weight, has an efficient keel, wide width for high stability and sail carrying power, and larger rig. All these features combine together to give a windward
performance better than any equivalent sized monohull. In a force 4 wind, a modern 60ft racing trimaran will sail upwind at 16 knots tacking through 75 degrees. While an open bridgedeck cruising cat like the Spectrum 42 will tack through 80 degrees, at around 10 knots.

The implications of this sort of performance is also an indication that modern multihulls will sail upwind in a gale long after the monohulls have had to heave to. Indeed this superior windward ability has been conclusively demonstrated in all the windward races of the North Atlantic and is a factor of major significance in the improved seaworthiness of modern designs.

**Safety in the event of collision or capsise**

Even though it has become extremely unlikely that a properly designed multihull will capsize, the possibility still exists, in much the same way as it exists for any monohull. The monohull's escape valve is that there is a chance that the boat will right itself before it sinks. The multihull on the other hand can be made into a safe raft for the crew to live on in the inverted position, provided that proper provision for this eventuality has been made at the design stage. In terms of ultimate safety of the crew in the most extreme storm - I believe that a habitable inverted multihull offers better survival prospects than a partially flooded - dismasted monohull that has rolled through 360 degrees, and is in imminent danger of doing so again.

If possible watertight compartments should be built in to the amas of a trimaran, and where ever possible in a cat. A trimaran can be made virtually unsinkable by making the cross beams watertight, and by dividing the ama up into watertight compartments, in such a way that if any section is holed, the remaining volume is over120% of the displacement of the main hull. The bows should be backed with foam, and a watertight collision bulkhead can usually be placed about 6 feet back from the bow, without affecting the accommodation.

The structural cross beams of a cat should be designed to be watertight, with their combined volume large enough to support the whole weight of the vessel. In the unlikely event of a capsise, this will ensure that the boat floats high out of the water, which reduces stress on the structure, and allows the crew to live in the upturned hull. I incorporate escape hatches in all my designs as a matter of course.

**Construction and Fatigue. - Integrated structure.**

During the lifespan of a multihull it is subjected to many cycles of a complex array of loads, and if the boat is to survive in all conditions without damage careful attention has to be paid to avoiding stress concentrations in the structure, and to the long term fatigue of the materials used to build it.
Fig 8 shows a generalised stress diagram for an open bridgedeck catamaran. By using a computer to analyze the loads at any point in the boat, and then laying appropriate amounts of fibers aligned in the direction of the stress, the stiffness and the strength of the boat can be greatly increased. While at the same time weight can be saved by removing excess material where it is not required. This weight saving actually increases the strength of the boat, because it not only reduces the loads that the boat experiences, but it reduces stress concentrations, which are a major cause of fatigue failure. If the structural design is carried out in this way, and adequate allowance is made in the fiber stress levels in the all parts of the boat to account for long term fatigue, the lifespan of the boat will be greatly increased. At present, research indicates that if a composite laminate can survive over 10 million cycles, it will last indefinitely. In general in order to achieve this, a factor of safety of at least 10 is required. In all my cruising designs I use at least 10 as a factor of safety in areas of maximum stress. For carbon in particular the laminate is strain limited because the material is so stiff, has a relatively low strain to failure, and an extremely high notch sensitivity. However the material can be very successfully used in areas where great stiffness is required, like the cross beams of a multihull. There are many racing and cruising multihulls sailing that have been designed in this way, and that have suffered no structural failure what so ever, in thousands of miles of hard ocean sailing.

Conclusion.

In the past 20 years the level of understanding of the factors that affect the seaworthiness of multihulls has increased enormously. Accidents and failures are an inevitable part of the development of any idea, but I hope that the above discussion makes it clear that there are many different types of multihull, and that a mishap in one type does not necessarily imply that all multihulls would have suffered the same fate in the same circumstances. Indeed many of the problems and vices associated with the older designs have now been
eliminated, and the new generation of cruising designs are very exciting boats to sail, while still offering vast accommodation, crew comfort, and most important of all - safety at sea.

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References


Articles.

8. Multihulls on Performance. J. Shuttleworth. Multihulls vol.10 no.1 Jan/Feb '84 (53-55)
9. Hull Shapes and Resistance to Motion in Cats and Tris. J. Shuttleworth Multihulls vol.9 no.1 Jan/Feb '83 (51-54)
10. Multihull performance Comparison and Rating Rules J. Shuttleworth. Multihulls vol.7 no.3 May/Jun '81 (43-45)

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