Multihull Stability

The capsize of a sailing trimaran prompts a critical look at the new code of practice

By Barry Deakin*

The publication of the Code of Practice for the safety of small commercial sailing vessels, by the U.K. Department of Transport in 1993, saw the introduction of stability requirements for sailing multihulls. The code of practice applies to vessels engaged in commercial use such as for sailing tuition, adventurous sail training, or charter.

The number of multihulls involved is relatively small in comparison with the monohull fleet, and was not addressed in the previous Code of Practice for sail training vessels, which was published in 1990. For that code the stability requirements for monohulls were developed by the Wolfson Unit following extensive wind tunnel tests and trials measurements which are described in Reference 1. The stability characteristics of multihulls are fundamentally different however, so the DTp based their requirements on a different philosophy.

One of the principal conclusions of the Wolfson Unit's studies was that it is not possible to calculate the wind heeling moment of a sailing rig with sufficient accuracy to predict steady heel angles under sail or heel responses resulting from gusts. Variations in wind heeling moments of plus or minus 40% are easily produced by changes in sail sheeting and camber. Despite this the multihull stability requirements use as their basis the traditional calculation of wind heeling moment, and balance this against the static righting moment of the hulls, to determine the wind speed which will result in capsize. Is it justifiable to use a method for multihulls which was abandoned as unreliable for monohulls?

Interest was further aroused at the Wolfson Unit in December when the trimaran *Triharda* capsized in Christchurch Bay with a crew of three including a former employee, Steph Merry. The incident attracted much media attention as another female crew member remained in the cabin for over six hours while the inverted yacht drifted, and then was towed to shelter to enable divers to assist her escape. Steph and the yacht's owner were able to remain relatively dry on the upturned vessel, release distress flares and await rescue.

Ian Farrier, the American designer of the F-27, kindly released drawings to enable calculations to investigate the stability and to enable an assessment using the procedures required by the code. A stability curve was calculated using the Wolfson Unit's own stability software which models correctly the buoyant forces and moments of multihull forms. The curve is presented in Figure 2 along with stability curves for three other sailing vessel forms for comparison. This trimaran's stability curve can be seen to fit within a progression from monohulls, with relatively low GM and a large angle of maximum GZ, to catamarans, with very high GM and very low angle of maximum GZ.

Fig 1. An F-27 trimaran. Pic: Ron Isles Productions.

Traditional cruising yachts with narrow beam and high ballast ratio have low initial stability and sail at heel angles of up to about 30 degrees. They are able to do this in safety because, if struck by a gust and heeled to a larger angle, the stability increases while the wind heeling moment for a given wind speed decreases. Indeed the stability reaches a maximum at around 80 or 90 degrees when the coachroof is immersed and the keel emerges from the water. The wind heeling moment has then reduced to a negligible value, the sails being in the water. It may be concluded that it is not possible to capsize a well ballasted monohull by wind alone. Yachts in the Whitbread 60 class achieve greater initial stability with a wide beam and all of their fixed ballast in a bulb on a deep fin keel. This enables them to carry a relatively powerful sail plan and to retain a large angle of maximum GZ and a good range of stability.

Catamarans carry no ballast and rely on the wide separation of the hulls to provide very high initial stability. The stability reaches a maximum at the angle at which the windward hull emerges from the water. The stability then reduces to zero at around 90 degrees, with the shape of the GZ curve dominated by a cosine function. For the example illustrated the stability reaches a maximum at 6 degrees and the vessel must be sailed at heel angles well below this value to retain a margin of safety. Most multihull sailors are aware of these limitations, but the problem they face is how to judge their level of safety at a given time, since the angles involved are too small to be measured on board. If the windward hull leaves the water a capsize is likely since, although the righting moment reduces at a similar rate to the heeling moment, the latter might still be significant at 90 degrees, with one hull and the bridge deck standing high above the water surface.

The outrigger floats of *Triharda* each have a total buoyancy equal to 110% of the vessel's displacement. It might be expected therefore that as the heel angle increases, the vessel will be supported on a single float, and the stability will reach a maximum value as the main hull emerges from the water. In fact, because the floats are centred forward of the LCG of the vessel, to reduce the likelihood of burying the leeward bow and pitchpoling, the vessel has a large trim at 90 degrees with the stern of the main hull in the water. The stability curve peaks at 22 degrees and reduces to zero at 80 degrees. The difference in range between it and the catamaran is dependent on the details of the float arrangements and centre of gravity heights, and is largely academic. The extreme stern trim indicated by the calculations was confirmed by Steph, who recalled rolling from her seat in the leeward aft corner of the cockpit, directly into the water which was around the coaming. She was not thrown through the air over the leeward float.

GZ curves are normally used to assess stability because they are generally independent

*Barry Deakin is with the Wolfson Unit for Marine Technology and Industrial Aerodynamics.

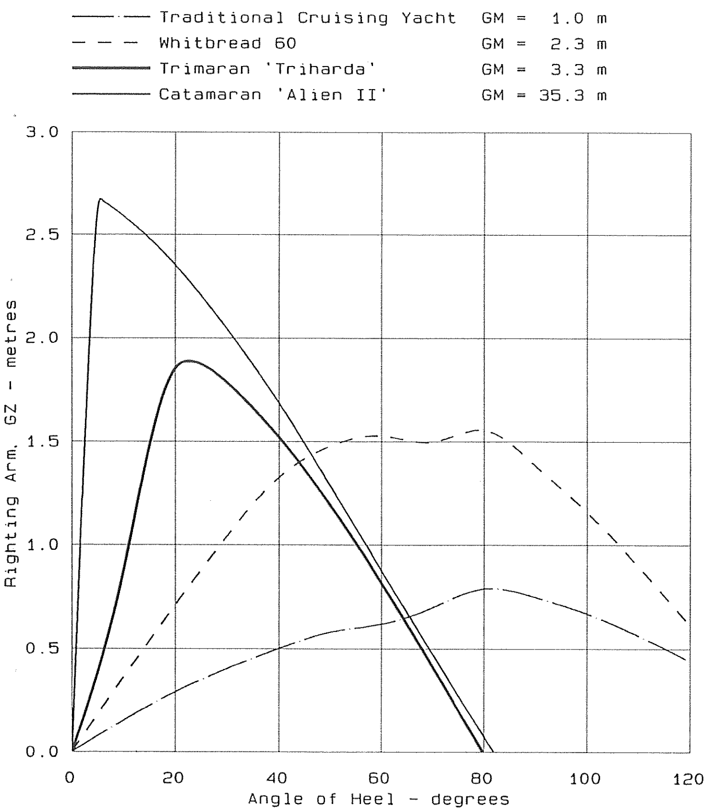

Fig 2. *Comparison of the stability of four sailing vessel forms.*

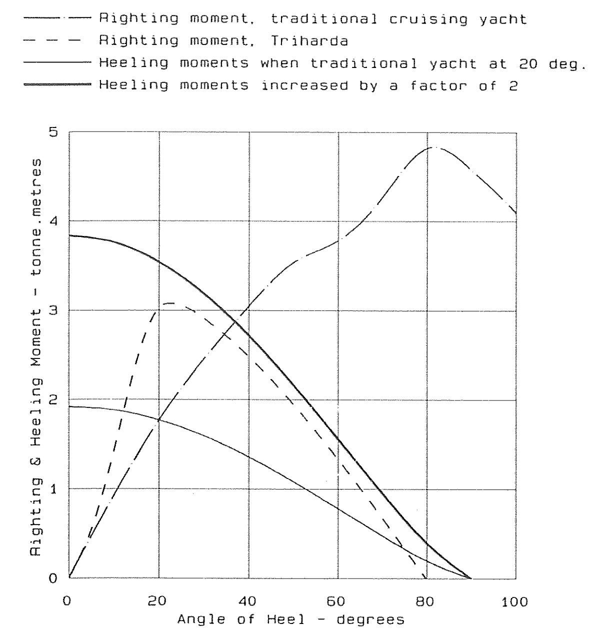

Fig 3. The effect of increasing the heeling moment on a traditional cruising yacht and Triharda.

of vessel size and enable a quick comparison of a vessel's characteristics with some accepted standard.

Conventional wisdom would indicate that the trimaran has considerably greater initial stability than the traditional monohull, its GZ curve having a steeper gradient at the origin. It has a much higher maximum GZ, 1.9m compared with 0.8m for the monohull, and it has a greater area under the GZ curve. These are the parameters normally used for assessment and indicate that from a stability point of view the trimaran is better by a large margin. The low angle of maximum GZ has always been a problem when multihulls have been assessed against conventional standards, but their substantial GZ values have been accepted as providing sufficient compensation.

When considering the effects of an external force however, the effect of displacement should not be discounted. The traditional cruising yacht whose stability is illustrated for comparison is a yacht of 9.75m with a displacement of 6.1 tonnes. *Triharda* is 8.25m with a design displacement of 1.63 tonnes. Despite these differences the vessels both carry the same working sail area of $42m^2$ and it may therefore be assumed that their wind heeling moments will be similar.

The righting moment curves for the two vessels are presented together in Figure 3 and provide a rather different comparison to those of righting lever in Figure 2. Both have a similar initial gradient because the product of displacement and GM for the trimaran is 5.4 tonne metres, while that for the monohull is 6.1 tonne metres. The stability of the trimaran increases more rapidly to a maximum value of 3.1 tonne metres at 21 degrees, at which angle the monohull has a righting moment of only 1.8 tonne metres. While the stability of the trimaran reduces to zero with further increase in heel angle, the monohull's righting moment continues to increase to a maximum value of 4.8 tonne metres at 80 degrees. The monohull can therefore resist a much greater maximum heeling moment than the multihull.

If we imagine the two vessels sailing with the same rig and the same apparent wind speed a common heeling moment curve can be drawn. The heeling moment curve due to a steady wind drawn in Figure 3 will cause the monohull to heel to 20 degrees, and *Triharda* to heel to 12 degrees. If we then assume that a gust increases the wind speed by a factor of 1.4, and hence the wind pressure by a factor of 2, assuming that the sail sheeting remains unchanged, the monohull will heel to 37 degrees but the multihull will not have sufficient reserve of stability to balance the increase and will capsize. This scenario neglects the various actions which could be taken by the crew, and the dynamic effects such as acceleration and increased dynamic lift on the leeward hull, but it is possible that the vessel may be stationary or caught by a squall which dramatically alters the apparent wind direction, or results in a much greater increase in the wind pressure. The example is by no means extreme therefore.

When *Triharda* capsized she had been running before a strong breeze of Force 6-7. The helmsman was thrown off balance, probably by impact with a breaking wave, and the yacht broached. It was then beam on to the wind and travelling at considerably reduced speed. The apparent wind speed therefore increased by a large factor, perhaps as large as 2, with an increase in wind pressure equal to the square of that factor. This incident illustrated that multihulls can be less forgiving of an error of judgement on the part of the crew, because a monohull in similar circumstances would merely suffer an uncomfortable roll. Whilst that might be unpleasant for the crew, it would not pose a threat to the yacht.

In order to assist the crew of a multihull with an indication of their level of safety, the code of practice sets out to calculate the wind heeling moment required to capsize, and then predict the apparent wind speed which would generate that heeling moment for the full sail plan and a number of reduced sail configurations. To allow a safety factor for gusts, the crew are provided with a maximum advised apparent wind speed for each sail plan which is 2/3 of the value which would cause a capsize.

To calculate wind heeling force the code uses the formula: Force (Newtons) = $0.20\,A\,V^2$ where A is the profile area of sails, mast and hull, and V is the wind speed in knots. This implies a heeling force coefficient of about 1.2.

Using this formula, and the reduced sail plan which was set at the time of the incident,

Fig 4. A model monohull yacht in the wind tunnel for gust heeling tests by the Wolfson Unit.

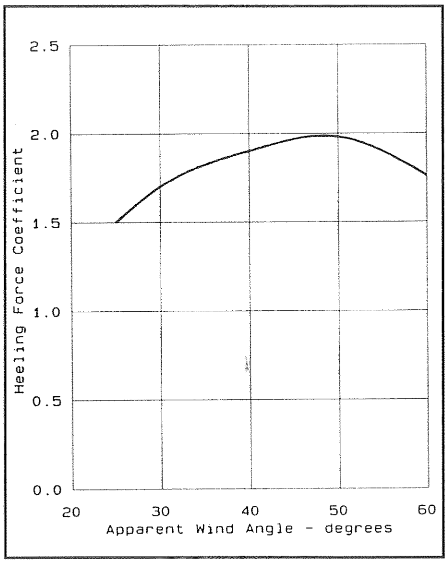

Fig 5. Heeling force coefficient at a range of apparent wind angles. Data derived from wind tunnel tests on the rig in Fig 4.

suggests a wind speed to cause capsize of 33 knots. This is at the upper limit of Force 7 and might seem reasonable but the main sheet was fully eased with the boom against the shrouds and, when broached, only the jib would have been filled. Numerous research and consultancy projects conducted by the Wolfson Unit have included wind tunnel tests to investigate the performance of various sailing rigs. A typical model is illustrated in Figure 4. Such tests repeatedly indicate that, whilst heeling force coefficients are highly dependent on sail camber and sheeting, they frequently exceed the value 1.2, particularly with modern high performance rigs and fully battened mainsails. Figure 5 presents typical data from tests on a rig similar to those carried by modern multihulls, and indicates heeling force coefficients of up to 2.

The calculated maximum windspeeds may therefore be misleading and suggest to crews a greater margin of safety than really exists. The code requires that the maximum advised wind speeds be tabulated for all anticipated sail configurations, and posted in the cockpit as an aid to safety. We need to be certain, therefore, that they do provide a realistic safety margin if crews are expected to use and respect the data, and benefit from them.

The code of practice categorises multihulls on the basis of the maximum advised windspeed, and each category is limited to operation within a specific distance of a safe haven, as defined in Table 1. For *Triharda* with the full main and genoa set the maximum advised windspeed is 16 knots, which enables it to operate up to 150 miles from a safe haven, and makes open crossings of up to 300 miles a possibility. The authorities must therefore ask themselves whether a vessel with these stability characteristics is suitable for commercial operation, perhaps carrying fee paying novices among the crew, at perhaps 12 hours from a safe haven.

The designer, Ian Farrier, was frank in his response to the question of suitability of the design for sailing offshore: "In regards to the F-27 making trans-ocean passages (two Atlantic and three Pacific) please be aware that such crossings are not encouraged or recommended. The individuals concerned made their own decisions to do such crossings. My only true ocean crossing design is the new F-36, which does have a lower wind capsize figure than the F-27. With a multihull, seaworthiness is much more dependent on the crew, and I and many others (particularly in Australia) have sailed my designs in winds in excess of 30 knots with full sail, including spinnaker. I have never come even close to a capsize, but obviously the risk factor is much higher in such conditions".

TABLE 1

Permitted area of operation	Code Category	Minimum acceptable value for Maximum Advised Mean Apparent Windpseed (knots) for minimum displacement condition
Unrestricted	0	18
Up to 150 miles from a safe haven	1	16
Up to 60 miles from a safe haven	2	14
Up to 20 miles from a safe haven	3 4	12 10

TABLE 2

	Triharda	Alien II
LOA	8.25 m	10.65 m
LWL	8.00 m	9.40 m
Beam	5.82 m	6.40 m
Draught (hull)	0.36 m	0.33 m
Draught (board down)	1.50 m	1.30 m
Mast height	12.65 m	13.6 m
Sail Areas		
Main	25.1 m^2	26.5 m^2
Jib	16.3 m^2	10.4 m^2
Genoa	22.9 m^2	22.4 m^2
Displacement	1.63 tonnes	2.00 tonnes

Steph Merry, who in 19 years of competitive offshore sailing has accumulated considerable multihull experience, had been helming *Triharda* until shortly before the capsize, and is of the firm opinion that she would not venture offshore in a vessel of that type.

The F-27 design incorporates an innovative folding float mechanism which enables it to be transported by road trailer or moored on a monohull marina berth. It was obviously not designed for commercial operation offshore, and is an unlikely candidate for such use. It remains a fact however, that such a yacht is currently deemed suitable, on the grounds of stability at least.

The traditional monohull yacht featured in Figures 2 and 3 would be required by the code to have a range of positive stability in excess of 140 degrees if operating in Category 1. This is to ensure prompt recovery from capsize by a breaking wave which, for such a small vessel, is a real possibility if caught offshore in a storm. This requirement also ensures that capsize by the wind is not possible. No conventional multihull could meet such requirements, and the arguments for treating them in a different way have been accepted because their GZ curves indicate them to be so stiff in comparison to monohulls that they have been assumed to deserve a different approach.

The more realistic comparison of Figure 3 must, however, force the authorities to ask why they should be treated differently. The question of whether they are immune to capsize by breaking waves is a separate subject and one on which there are few facts and perhaps no simple answers.

Multihulls are certainly vulnerable to pitchpoling, when the leeward bow is buried in a wave and the increased drag causes a dramatic reduction in speed and thus an increase in apparent wind speed. The result can be a diagonal capsize.

The catamaran *Alien II* featured in Figure 2 is a David Alan-Williams design of 10.65m overall length with hull centrelines spaced 5.5m apart. It is a high performance craft with a displacement of 2 tonnes and a sail area of $49m^2$. It is thus a little larger than *Triharda*, with an equivalent sail area in proportion to the $(displacement)^{2/3}$.

A stability assessment in accordance with the code of practice revealed that it would qualify easily for operation in the unrestricted category, having a maximum advised wind speed of 20.5 knots, and requiring 31 knots of wind to capsize it.

In fact *Alien II* was also a stability casualty, and capsized in the Solent in force 5-6 conditions. This suggests a mean wind speed of around 20 to 25 knots, perhaps with gusts of over 30 knots. The crew were apparently trying to sail with the windward hull out of the water and did not respond correctly to a gust.

Steps must be taken to ensure that commercially operated vessels are not vulnerable to such human error, and perhaps the tabulated list of maximum advised windspeeds is the best approach.

Apparently the adopted method leaves little room for error, particularly when one considers that the assumed heeling force coefficient may under-estimate by up to 60%, and perhaps a greater factor of safety should be incorporated.

In defence of multihulls, they have a greater potential to provide a survival capsule than a conventional monohull, since they carry no fixed ballast and are likely to remain afloat if capsized or damaged.

The code of practice requires that new multihulls be designed to float for more than 12 hours after capsizing, regardless of their category of operation. It is not explained how this should be achieved or demonstrated however, and our experience at both model and full scale suggest to us that such theoretical calculations are not possible since there are so many variables including small undocumented leaks. (see "Trawler Sinking Tests at the Wolfson Unit", *S&B* April 94). There is no requirement for escape hatches in the underside of the hulls, so the value of the stable but inverted vessel in the open ocean, in strong winds, is doubtful.

Most people involved in the yachting industry are aware of the current pressures for increased regulation. The code of practice introduced by the Department of Transport, now the Marine Safety Agency, is to be followed by an EU Directive on Recreational Craft, and many people fear further restrictive regulations. These fears will be justified if the authorities do not understand fully the underlying principles, or the implications of their requirements. Without careful development the regulations will not identify those vessels which offer lower levels of safety, they will not be respected by the industry, and they will not save lives.

It appears that those currently involved in the development of the various standards are becoming increasingly concerned with detailed and complex calculations, which make life tedious for the designers and authorities but do little to increase safety.

We do not have a problem at present with commercial multihulls capsizing offshore, but how many commercial sailing multihulls are there? Perhaps if there is a rise in popularity of multihull sailing, and it is undoubtedly the light, high performance yachts which offer the most excitement, we may see some operators sailing well within the rules but very close to the edge in terms of safety from capsizing. If the regulations are deemed to be necessary, then they should incorporate the latest research findings in the simplest effective way. It is unfortunate, if inevitable, that regulations are believed to be adequate until a casualty reveals otherwise.

References

The Development of Stability Standards for UK Sailing Vessels. B Deakin, RINA Spring Meetings 1990.

An article by Dr Merry which gives a full account of events leading up to the capsize, and the subsequent rescue, appears in the August '94 issue of 'Multihull International.'

Comments by Dr Stephanie Merry, I.S.V.R., University of Southampton

This paper presents a valuable analysis and comparison of the stability of different types of sailing craft. As a member of the crew on board the F27 trimaran *Triharda* which capsized on December 11th last, I was surprised to learn that:

i) the stability requirements for sailing multihulls in the Department of Transport Code of Practice do not take wave action into account.
ii) the F27 falls into Code Category 1, with a permitted area of operation of up to 150 miles from a safe haven.

At the time of the capsize, *Triharda* was sailing in extremely confused seas, with breaking waves, on the outer edge of Christchurch Ledge. Wave action not only threw the helmsman off balance, causing the yacht to broach beam on to the wind; a subsequent breaking wave then lifted the weather float well past the 21° angle of maximum stability for the vessel. Any multihull will be vulnerable to capsize under such circumstances.

With regard to the 'permitted area of operation' of the F27, I fully endorse the designer's comment that the seaworthiness of a multihull is dependent on crew ability and reactions. My own multihull sailing is almost exclusively in 'Peaks Racing' (short-handed, combined running and sailing), where crew exhaustion and a slow response time is an important factor. For these events I therefore prefer the extra margin of safety offered by larger multihulls. It is of great concern that the Code of Practice suggests that operation of a craft as small as the F27 in open water, 150 miles from a safe haven, is advisable, without regard for the crew skills and experience.

The concept of an upturned multihull as a survival capsule is worth further consideration. We did not have a liferaft on *Triharda* for the inshore passage from Poole to Chichester, relying instead on an inflated dinghy, lashed to the netting for easy access. While awaiting rescue on the upturned hull, I considered its merits relative to a liferaft. It formed a stable platform for the skipper, Nic Slocum, and myself;

we stood on the netting and leaned against the hulls, so only our feet were awash. Additionally, the large area formed by the hulls and netting was more visible to the rescue services than a liferaft. *Triharda* did not lose buoyancy during the 6 hour rescue period, nor, I understand, during the subsequent 12 hours prior to righting the vessel in Yarmouth Harbour. This suggests that floating for 12 hours, as required by the Code of Practice, would not be a problem if the floats remain intact.

The disadvantage of the inverted hull, as compared to a liferaft, is that it offers no protection from the elements, unless an escape hatch is fitted. The absence of a requirement for this facility in the Code of Practice is disturbing; "viable means of egress from and access to accommodation in the event of capsize'' is required by the Multihull Offshore Cruising and Racing Association (MOCRA) for offshore races where 'a high degree of self sufficiency is required of the yachts' – typically 150-200 miles and well within the permitted area of operation for multihulls in Category 1 of the Code.

The capsize of the *Triharda* attracted media attention because a young woman was trapped inside the hull for several hours. Had she been able to egress from the hull via an escape hatch, her own trauma would have been largely mitigated and media interest short-lived.

Fortunately we were rescued before dark; it is unlikely that Nic and I would have survived a December night at sea on an exposed hull. In such circumstances an escape hatch would have given us access to shelter from the elements, inside the cabin.

Barry's article has raised some important questions regarding current regulations for multihull stability. I support his view that existing standards may not increase safety and trust that the standards will be developed to incorporate other factors and research findings, as outlined in this paper.