stability assessment

– the state of the art

In February's Seahorse Barry Deakin concluded with a criticism of the progress that is being made in yacht safety. Here he reviews the means of stability assessment employed by various organisations

Yacht designers have traditionally been concerned with the provision of a seaworthy cruising vessel with adequate sailing performance. Yachts evolved from working craft such as fishing or pilot vessels, the characteristics of which were well known. Designers have gradually modified these forms and, by slowly changing parameters, remained confident of their stability and seaworthiness.

With the growth of sailing as a competitive sport, yacht design and construction has progressed in the direction of performance, often at the expense of the other qualities. The design of racing yachts is dominated by rating rules. The traditional rules of thumb over stability issues have become obsolete in the racing yacht design office and are sometimes also neglected with modern cruising yachts. Modern racing yacht forms have many benefits in terms of interior volume and performance, and so market pressures have inevitably brought about their use as the basis for many cruising hulls.

Designs have therefore recently diversified considerably, as have stability properties. Various regulatory authorities have sought ways of assessing the safety of yachts in terms of stability. Methods of calculation and stability requirements have been under review in recent years, with much debate over what constitutes 'good stability' or 'sufficient stability'.

A considerable amount of research was carried out after the 1979 Fastnet Race which led to a much improved understanding of capsize mechanisms. Research concentrated on capsize as a result of an encounter with a breaking wave, since this was the principal mechanism reported by the Fastnet casualties. One important conclusion was that yachts with a range of stability over about 150° would not remain inverted following a capsize, the inertia of the roll or subsequent wave motion being sufficient to right the yacht.

Traditionally, small cruising yachts had a range of stability of at least 150° and would normally return upright if capsized. Nowadays, however, such a range requirement is generally considered to be unnecessarily conservative, and is certainly not readily achievable with a modern hull form. In general, traditional narrow, deep forms were more resistant to ▶

Yacht Stability Data on Wolfson Unit Files and the Minimum Required Ranges for the Department of Transport's Code of Practice

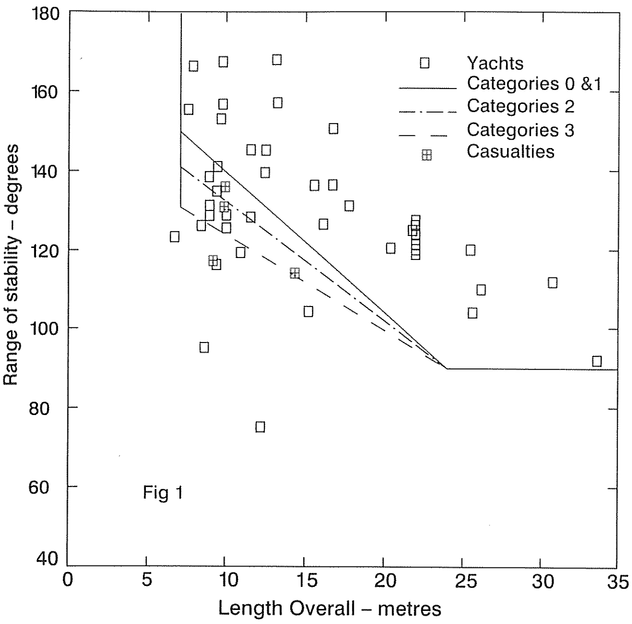


Fig 1

capsize, but breaking wave height in relation to boat size is still the overriding factor – large yachts being safer in a given sea state since they are less likely to encounter a breaking wave of a size that could result in capsize.

Being knocked down by a gust, or broached in a following sea can result in a yacht heeling beyond 90°, particularly if a spinnaker is being used. This may result in the mast touching the water, at which point the wind heeling moment is reduced to a fraction of its upright value, and the rig striking the water tends to arrest the roll. For a traditional yacht this would occur at about 90°, but for a modern beamy light-displacement yacht the mast may not reach the water until an angle of 100° or 110° has been reached – at which point without a positive righting moment the yacht could become inverted or lie on its side.

All large design offices now have the facilities for computing stability characteristics of new designs and many incorporate a calculation of the range of stability into the design process. Not all of these computer programs are able to include the effects of coachroof and cockpit, however, factors which are fundamental to stability at very large angles. There are many individuals and small companies involved in yacht design who do not have such facilities. If they are involved only in cruising yacht design it is unlikely that they will commission a consultant to produce stability data, there being no legal requirement or public demand for such information.

Yacht designers tend to rely on their calculations for displacement and centre of gravity location. Inclining experiments, which are used to measure these values accurately, are virtually unheard of for cruising yachts, unless of course the yacht undergoes an inclining measurement for racing purposes. Since there have been no stability regulations for yachts, some designers have adopted their own targets, generally regarding a range of stability of about 120° to be the basic requirement – a value that may simply have been selected as a result of considerable publicity given to the USYRU recommendations in the mid 1980s.

The surest way to satisfy a regulatory authority of the adequacy of the statistical stability characteristics is to use the conventional procedure of detailed calculations and an inclining experiment. Calculations must include the effects of the keel, cockpit, coachroof and any other significant features which affect the buoyant form of the yacht. It is essential that stability calculations be performed with the yacht free to trim as it heels, particularly with a modern design featuring a wide transom and maximum beam well aft.

What allowance to make for crew weight and position is the subject of much debate. For performance purposes the crew weight is considered at its normal location on the yacht, but when calculating the stability to assess the yacht's range and self-righting ability, the positive – or negative – effect of the crew's position becomes difficult to define. At the Wolfson Unit crew weight is usually neglected in such calculations.

There has been a reluctance on the part of rating authorities to demand detailed stability calculations from racing yacht designers. Until perhaps 20 years ago the technology was not readily available, but more recently specific stability requirements could have been incorporated. Fears of additional cost and the problems associated with the approval of results have perhaps deterred many designers.

The IMS includes a calculation of the stability curve for the hull only, but this is derived by the rating authority from detailed hull-only measurements. The resulting range of stability is typically pessimistic, since the omission of the coachroof is a major flaw in the calculation. Initially, the rule required a minimum range of just 95°, but IMS statistics indicated in 1989 that the average range of stability of the fleet was decreasing and the minimum value was increased to 103°. Even allowing an additional 10° or 20° for the buoyancy of the coachroof, this requirement inspires little confidence.

With the introduction of the Whitbread 60 and revised regulations for the Whitbread Maxis comes the first requirement for an accurate stability assessment for racing yachts. The Wolfson Unit is being commissioned to assess all Whitbread entries to ensure that their range of stability is at least 125°.

The only UK cruising yachts currently required to satisfy stability criteria are those which are more than 15m long and engaged in sail training. Smaller sail training yachts may be assessed by approximate methods but if they fail to meet the requirements, an accurate investigation of their stability may be used as an alternative. These Department of Transport (DTp) requirements are detailed in the 1990 Code of Practice for Sail Training Vessels which is now under review. They originated from the Wolfson Unit's proposal for a minimum range requirement as a function of length, but considerable discussion ensued between representatives of the sail training industry and the DTp, resulting in some relaxation of the criteria for yachts operating in restricted areas. Figure 1 presents graphically the requirements as defined in the Code of Practice. Yachts in Category 3 are restricted within 15 miles of the coast of the country of operation, those in Category 2 to the Near Continental Operating Area, and those in Category 0 are unrestricted.

Category 1 permits operation in the Extended European Operating Area and requires the same standard of stability as Category 0.

Also shown in Figure 1 are actual values for yachts on which inclining experiments have been conducted, and for which the Wolfson Unit have reliable data. The data include a variety of yachts. In general the samples fall into three groups:

a. A diagonal band well above the minimum requirement, comprising traditional cruising yachts and large racing yachts;

b. A group around 10m long with a range between 115° and 140°, mainly comprising contemporary yachts influenced by rating rules;

c. Scattered examples which fall well below the minimum requirement principally because of significant modifications which have reduced their stability.

Four casualties are also highlighted, the largest one being Taka which remained inverted after a breaking wave capsize (see *Seahorse* February).

Being reluctant to demand accurate proof of adequate stability, yacht racing authorities have gone to considerable lengths to develop approximate methods of assessment. The earliest was a screening value introduced to the IOR which estimated the value of the righting lever (GZ) at 90° of heel. A minimum value of three inches (75mm) was required, but this would ensure a range of about 100° and so was virtually worthless in terms of safety in breaking waves.

The RORC introduced a more complex system known as the Stability and Safety Screening Calculation Scheme (SSSCS) to their CHS. Their screening value comprises a base value, derived from rated parameters, summed with an adjustment value which is dependent on safety-related features such as the size of openings, provision of integral buoyancy, and cockpit drainage arrangements.

Base Value = FBS x FDL x FBD x FSDBL x FSR x FR x FK x FEP x FDAY where FBS, the 'base size factor' is a measure of length, greater length being assumed to provide greater safety. The remaining factors all have values close to unity and hence modify the base size factor.

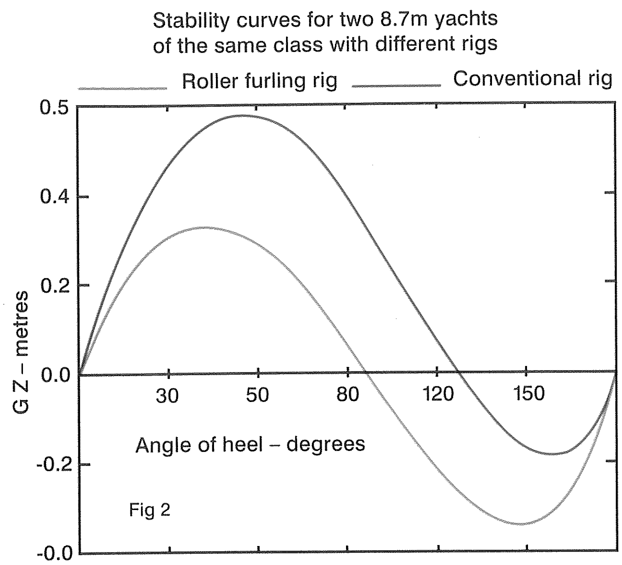
FDL – Displacement Length Factor; FBD – Beam Displacement Factor; FSDBL – Sail Area Displacement Beam Length Factor; FSR – Self Righting Factor; FR – Rig Factor; FK – Keel Factor; FEP – Engine & Propeller Factor; FDAY – Dayboat Factor.

Each factor is calculated using a formula derived to assign the appropriate importance to the parameters considered, and limits are put on the factors. The factors incorporate a number of other screening value formulae such as that used by the IOR, but none incorporate the beam/draught or beam/ depth ratio, which research has highlighted as fundamental to real-life large-angle stability.

Some factors have a doubtful effect. For example the beam/ displacement factor (FBD) penalises a boat with narrow beam. Since yachts of similar size carry similar sail plans, a yacht with narrow beam requires more ballast to obtain the necessary righting moment to hold the rig and sail efficiently. Whilst the initial stability (GM) may be low, this only affects ▶

P.45: Merit during the 1989/90 Whitbread and Flyer (above) during the 1981/82 Whitbread. The Wolfson Unit will stability screen this year's Whitbread entries

Photographs, P.45: Philippe Schiller; above: Onne Van Der Wal – PPL



the amount of sail that can be carried and does not prejudice the range. In fact, narrow yachts, because of their high ballast ratios, usually have excellent ranges of stability and should not be penalised on the grounds of safety.

This system appears to be gaining in popularity despite its unwieldy nature (it requires a computer program to determine the value from rating parameters). Perhaps it is this same complexity which convinces the authorities that it is technically sound. The method has, for example, been incorporated into the Department of Transport's Code of Practice, modified to include a further factor based on yet another approximate method. This latter approximation is the range estimate method of assessment proposed by the Wolfson Unit for use with existing cruising yachts seeking DTp approval for sail training. A simple example formula was proposed from which a pessimistic estimate of the range could be derived. If a yacht could meet the minimum requirement on the basis of this low estimate it would be sure to pass on the basis of an accurate assessment. One expense of approval would thus be avoided by existing traditional yachts with very good stability characteristics. Unfortunately, pressure from the industry forced the DTp to revise the formula to give a more optimistic value of the range, while at the same time the minimum requirements were reduced. The result is that some yachts have been able to meet the requirements by the use of approximate methods, when they would undoubtedly be deemed unsuitable if examined accurately.

An illustration of the dangers of approximate assessments is given by a comparison of the stability curves for two examples of a class of 8.7m production cruising yacht in Fig. 2. The yacht with a range of 127° has a conventional rig as designed. The other with a range of only 96° has had a mast furling mainsail and roller furling headsail fitted. The additional weight aloft on this yacht has reduced its range by 31°. The only way to identify such effects accurately is with an inclining experiment and a conventional stability calculation.

Thus there are two aspects to stability assessment: the range needs to be determined properly and there needs to be a sufficiently conservative minimum requirement. If an approximate method must be used an increased factor of safety should be introduced.

That these criteria are not being met has been demonstrated by the recent capsize of Taka. In 1979 a yacht with a range of stability of 117° capsized and remained inverted for several minutes, and two crew died. The capsize mechanisms and means of minimising them have been well researched and documented but not built into the regulations. Thus in 1991 Taka, a yacht with a range of stability of 114°, capsized and remained inverted for about three-quarters of an hour with the subsequent death of six crew.

Yacht racing will never be 100 per cent safe, but if the authorities wish to minimise the likelihood of incidents such as these, the knowledge and techniques are there and are available at an acceptable cost. ●

Barry Deakin works for the Wolfson Unit. His duties there include stability investigations on all types of craft, conducting towing tank and wind tunnel tests and troubleshooting on a variety of naval architectural and aerodynamic problems.

High Risk

Top racing yacht builder Rob Lipsett believes that it is not just in the area of stability that we should be paying more attention to safety

Modern racing boat construction is a high-risk venture. From the toxicity of the building environment, to the potential structural failure of the end product – there are many factors that can combine to spoil your day.

Much is heard about the apparent lack of robustness of the current high-tech race boat; the first question generally raised being 'Are they strong enough?' The simple answer is no. 'What!' I hear you cry, 'Not strong enough?' This is certainly true, but the majority of people involved now know and accept this. So how exactly have we got ourselves into such a predicament?

One of the major problems is the pressure to win, which inevitably leads to risks being taken in order to save weight to make boats faster. Each raceboat will normally be tailor-made for a customer. In the past this did not usually lead to problems as the boats most likely to break were sailed by the best crews. In fact discussions with the owner, designer, builder and crew would normally agree the level of risk they wished to take. The problem has arisen as ever smaller safety margins have now become the norm rather than the exception. The result is that a crucial subject is no longer discussed in any detail, as no one now believes it will ever really be a problem.

This prognosis is based upon the fact that there haven't really been any problems to date – an arguable point. The reason there has not been a major disaster in races such as the Whitbread is probably one of weather, recent editions of this event having been blessed with relatively good conditions.

The latest One-Tonner my company built competed in the 1991 Fastnet Race. This boat was extremely light and in my opinion very well built. It was full-on high-tech: dry pre-preg carbon, with a full Nomex core. It was also designed to ABS. Not only was it designed to ABS, it was also built to ABS, unlike some others. She was therefore stronger than some, completely legal and definitely very breakable.

Had she not been in this unenviable position she would not have been as competitive as she was, since she would have been too heavy. If this is where the present rules and the policing of them has led us, then I for one no longer wish to be involved.

To highlight one particular area of concern, the main area of specific debate at the moment appears to focus on keels and their attachment. Here are a few of the more dramatic examples which have somehow resulted in only one death. Therefore to date we must consider ourselves to be very very lucky.

Fujicolor – a recent victim of delamination
Jacques Vapillon – DPPI

Drum England (IOR Maxi):	Keel comes off on Fastnet
Coyote (Open 60):	Bulb off, boat capsizes, crew missing
Spanish AC boat:	Bulb off, boat capsizes
Martela (IOR Maxi):	Keel off on Whitbread
Fleury-Michon (Open 60):	Keel works loose in Vendée Globe
Brooksfield (W60):	Keel bolts fail on Discovery Race
Groupe LG (Open 60):	Keel doubts cause Vendée - Globe retirement

So what's to be done about these construction issues? Unfortunately whatever we do will probably increase the cost of producing and sailing these boats. The W60s have gone some way to solving the panel strength problem by insisting upon core samples being taken during construction. However many more core samples could be taken without causing the builder a problem. Indeed, the boats could have a higher minimum weight, and could err on the side of safety and caution rather than being minimalistic. If all the boats of one class are the same, it doesn't really matter what the weight is. Not only should core samples be taken but the construction should be policed. It is unrealistic to rely upon the builder signing a set of drawings to say how the boat was built.

These core samples could also be used to enable a database to be compiled for use by the structural engineers. These samples could be checked for interlaminar bonding, core bonding and cure, thereby giving engineers the real state of the yachts as opposed to information gained from small laboratory samples. A sample 6in x 6in piece made under laboratory conditions by a man in a white suit and rubber gloves bears little or no resemblance to something 82ft long and 20ft wide.

The problem with the full-size item is that people walk on it and open doors around it. Whilst most boatbuilders will do their utmost to reproduce laboratory conditions as closely as possible, this is obviously unrealistic when the pressure grows to finish a race boat.

Another problem is that, in this age of litigation, most builders build boats exactly to the drawings irrespective of their feelings, to cover themselves. In the past many boats were modified on the shop floor to reflect the expertise of the builder. This gave a false impression to the structural engineer of the correctness of the original unmodified specification.

In order to move forwards the industry needs to establish a true database so structural engineers and designers have real data to work from. The rules should be strictly enforced and should include realistic minimum weights so that the boats are over rather than under built.

If some of us still wish to build extremely light and marginal boats, then it would probably be best if we turned our attention towards inshore multihulls and events such as the World Sailing Speed Record.

High risk is obviously a subjective term. Coming from someone whose company recently cut a Whitbread Maxi (Fortuna) into three pieces and put it back together again with 'insertions', the phrase risk itself is clearly relative! However, my personal opinion is that we are presently in a high risk situation with the real potential for a serious disaster such as the total loss of a Whitbread entry.

A simple rule of thumb should be that boats with navigation lights should be pretty bloody strong!

Rob Lipsett is the Principal of Vision Yachts, an English company that has been involved in the construction of many successful IOR yachts including Rothmans and Jamarella.