METHODS OF ASSESSING THE SAFETY OF CRUISING YACHTS IN TERMS OF STABILITY

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SUMMARY

This paper reviews the various methods in current use to assess the safety of yachts with regard to their statical stability properties. A number of approximate methods are described and compared with accurate stability investigations where possible.

The author has been closely involved in the development of the stability standards included in the Department of Transport's Code of Practice for sail training yachts, and the methods used therein are the subject of particular interest. In this first year of implementation of the code a large number of yachts have been certificated and these provide data for a statistical comparison of some methods.

1. INTRODUCTION

Yacht designers have traditionally been concerned with the provision of a comfortable and seaworthy cruising vessel with adequate sailing performance and ease of handling. Yachts evolved initially from working craft such as fishing or pilot vessels, the characteristics of which were well known. Designers have modified these forms gradually and, by changing parameters a little at a time, remained confident of their stability and seaworthiness. Many rules of thumb have developed over the years to guide decisions on such parameters as ballast ratio and sail area.

With the growth of racing as a sport alongside advances in materials technology, yacht design has progressed in the direction of performance, often at the expense of the other qualities sought in a cruising yacht. The design of racing yachts is dominated by the rating rules and these have influenced designers to produce the familiar modern shapes. The traditional rules of thumb are obsolete in the racing yacht design office and are sometimes neglected when modern cruising yachts are considered. Modern racing yacht forms have many benefits in terms of internal arrangements as well as performance, and market pressures have brought about their use as cruising yacht hulls.

Designs have therefore diversified considerably in recent years and, to the surprise of many people, their stability properties are equally diverse. Various regulating authorities have come to realise this and have sought ways of assessing the safety of yachts in terms of stability. Methods of calculation and stability requirements have both come under review in recent years, and numerous discussions have taken place on what constitutes 'good stability' or 'sufficient stability' for a yacht.

2. STABILITY REQUIREMENTS FOR SAFETY

A considerable amount of research was carried out in the 1980's, prompted by the 1979 Fastnet Race casualty list, which led to a much improved understanding of capsize mechanisms. This work is detailed in References 1 and 2. The work concentrated on capsize as a result of an encounter with a breaking wave, since this was the principal mechanism reported by the casualties. One of the important conclusions of this work was that yachts with a range of stability greater than about 150 degrees would not remain inverted following a capsize, the inertia of the roll or subsequent wave motion being sufficient to return the yacht to its range of positive stability.

Traditionally small cruising yachts had a range of stability of at least 150 degrees and would therefore always return to upright if capsized. Such a range requirement is generally considered by modern designers to be unnecessarily conservative, and is certainly not readily achievable with a modern hull form. Considerable attention was paid to various aspects of geometry and weight distribution which might affect the vulnerability to capsize. Whilst several aspects of design were found to have some influence, the effects were often so slight that a small increase in wave height would overcome any gains made. In general, traditional forms with narrow beam and a deep hull were more resistant to capsize, but breaking wave size in relation to boat size is the overriding factor. Larger yachts are therefore safer in a given sea state, since they are less likely to encounter a breaking wave of sufficient size to result in capsize. This fact has led to proposals for stability requirements which vary with size. Figure 1 presents three such proposals for comparison. The United States Yacht Racing Union were concerned primarily with offshore racing yachts of 6 to 12 metres in length. Their length parameter was not simply the overall length of the yacht, but an 'equivalent capsize length' derived by adjusting the length according to other factors thought to influence vulnerability to capsize. The RYA proposal was a tentative suggestion to the DTp for application to sailing school yachts, when the Code of Practice was first being considered. It was tendered for discussion rather than as a firm proposal. The Wolfson Unit's proposal similarly applied to yachts engaged in sail training and subject to Department of Transport approval.

Figure 1
Three proposals for minimum range of stability

Breaking waves are not the only cause of capsize, nor indeed the most frequent. Being knocked down by a gust, or broached in a following sea can result in a yacht being heeled to beyond 90 degrees, particularly if a spinnaker is being used. Such an incident 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 degrees, the waterline being roughly along the centreline of the yacht at that angle. For a modern light displacement yacht with a wide beam, the mast might not reach the water until an angle of 100 or 110 degrees has been reached. It is necessary for the yacht to have a positive righting arm at this point, or it might become inverted or lie on its beam ends and flood. It is a less onerous criteria than that required for survival of a breaking wave capsize however, and if there is a significant possibility of encountering a breaking wave the range of stability should have a suitable margin.

3. CURRENT DESIGN PRACTICE

Most large yacht design offices now have facilities for computing the 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, and these are of course fundamental to the 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, since there is no legal requirement nor public demand for such information.

Yacht designers tend to rely on their calculations for displacement and centre of gravity location,inclining experiments being virtually unheard of for cruising yachts, unless of course the yacht is also to be raced and undergoes an inclining experiment as part of its rating measurement. Since there have been no stability regulations for yachts, some designers have adopted their own targets and generally they appear to regard a range of stability of about 120 degrees to be the basic requirement. This value may have been selected as a result of considerable publicity given to the USYRU recommendations, rather than being arrived at independently by the individuals.

4. ACCURATE METHOD OF ASSESSMENT

The only way to determine the statical stability characteristics with any confidence in their accuracy 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 contribute to or deduct from 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 of midships.

The inclining experiment requires considerable care if an accurate result is to be obtained. The small vessel size and presence of the rig make a yacht highly susceptible to external disturbances and a calm day is required for the experiment. Those conducting the experiment should be aware that their weight is similar to that of the inclining weights and they must return to precisely the same location for each reading. When measuring freeboards to determine the waterline as inclined, it is common practice on a ship to walk around the deck lowering a tape measure to the water at a number of locations. If such a procedure is used on a yacht, the heel and trim resulting from the person's location might result in significantly reduced freeboards and an apparent displacement much greater than the actual value. His weight should be balanced by another person at the opposite end or side of the yacht, or alternatively the freeboards measured from a boat alongside, with no movement of personnel on board required. If a conventional damped pendulum is used, and this remains the simplest and most reliable means of determining the angle of inclination, it will be necessary for someone to be aboard during the experiment, but there is never any reason for more than two people to remain on the yacht while readings are taken.

What allowance to make for crew weight and position is the subject of 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 crew's effective position becomes difficult to define. In the event of a capsize the crew may all be in the water and have no contribution whatsoever. They may come to rest on the inside of the coachroof where, if they are holding on, their centre of gravity will have an adverse effect on the stability. They may be attached by lifelines to various points around the yacht, applying unknown heeling or righting moments depending on their location. It is normal practice at the Wolfson Unit to neglect the crew weight in such calculations.

5. DEMANDS FOR ACCURATE ASSESSMENT

There has been a reluctance on the part of rating authorities to demand detailed stability calculations from the designers of racing yachts. Until perhaps 20 years ago the technology was not readily available but more recently, with numerous computer programs available, specific stability requirements could have been incorporated into their rules. The additional cost to the designers and problems associated with approval have perhaps deterred them. The International Measurement System (IMS) developed in the USA includes a calculation of a stability curve for the hull only, but this is derived by the rating authority from detailed hull measurements rather than from the designer's drawings as would be the case for any type of commercial vessel. The resulting range of stability is typically pessimistic since the omission of the coachroof is the major flaw in the calculation. The rule requires a minimum range of just 95 degrees however, and this could be the actual range for a yacht without a coachroof. IMS statistics indicated in 1989 that the average range of stability of the fleet was decreasing, and suggestions were raised that the minimum value should be increased to, say 105 degrees.

With the introduction this year of the Whitbread 60 Rule comes the first requirement for a conventional, accurate stability assessment for racing yachts. The designers are required to produce evidence of a range of stability of at least 125 degrees for those yachts which will compete in the round the world race. In fact this rule also demands that the yachts satisfy some simple flooding requirements by subdivision of the hull, another first in the yachting world.

The only cruising yachts currently required to prove compliance with stability criteria are those in the UK which are more than 15 metres long and engaged in sail training. Smaller sail training yachts may be assessed by approximate methods but if they fail to meet the requirements of those methods, an accurate investigation of their stability may be used as an alternative to provide evidence of their stability. The

Department of Transport's requirements are detailed in their Code of Practice, Ref.3 and the development of these standards is described in Ref.4.

Following the Wolfson Unit's proposal for a minimum range requirement as a function of length, Figure 1, considerable discussion ensued between representatives of the sail training industry and the DTp, resulting in a modified form of this requirement which enabled some relaxation of the criteria for yachts operating in restricted geographical areas or categories. Figure 2 presents graphically the requirements as defined in the Code of Practice. Yachts in category 3 are restricted to 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 on Figure 2 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 racing and cruising yachts. In general the samples fall into three groups:

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

A group around 10 metres long with a range of between 115 and 140 degrees, mainly comprising contemporary yachts influenced by rating rules;

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

Figure 2
Minimum range of stability required by the Code of Practice for each regional category.
The yachts are those for which the Wolfson Unit has reliable inclining experiment data.

6. APPROXIMATE METHODS OF ASSESSMENT

Five approximate methods have been proposed by different organisations concerned with the operation of sailing boats. These methods include stability criteria as well as approximate methods of assessing compliance.

6.1 IOR Screening Value

When fears were first expressed that the IOR rating system was resulting in racing yachts with poor stability at large angles, the ORC introduced a screening value to the rule, with the objective that "all yachts rated under the IOR shall have sufficient stability to recover from a knockdown condition".

The screening value was defined as:

$$SV = K3\ ((0.03L \times BCOR^3 \times K - 54\ RM) / DSPL + 0.6\ CMDI - 0.54\ CMD) + 0.25$$

where: K3 and K are merely factors used to convert metric measurements to feet.

L is the rated length.
BCOR is the waterline beam, measured or estimated.

RM is the righting moment at 1 degree, derived from an inclining experiment.
DSPL is the displacement, estimated.
CMDI is the draught of the canoe body.
CMD is the depth of the canoe body.

In normal naval architectural parlance, the first term of the formula is an estimate of waterplane inertia on displacement, that is BM. The second term is an estimate of GM, the constant 54 being 1/sin 1 degree multiplied by the factor 0.94, because DSPL is typically 6% less than the true displacement. The third term gives an estimate of the VCB and the fourth term is an estimate of the centre of buoyancy location relative to the underside of the canoe body, when at 90 degrees of heel.

The formula may thus be reduced to:

BM - GM + VCB upright - VCB at 90 degrees

that is VCG - VCB at 90 degrees

At 90 degrees this is equal to GZ in magnitude, but of opposite sign. The value 0.25 is therefore added in the formula and if the resulting value of SV is zero or negative the yacht's estimated GZ value at 90 degrees is greater than 3 inches and considered satisfactory. With such a GZ value at 90 degrees, the range of stability is likely to be around 100 degrees and, while this may be just sufficient to recover from a knockdown it will not ensure recovery from a breaking wave capsize.

The success of the formula in predicting GZ values depends on all yachts having similar shapes. This is of course the case with most modern designs to the IOR, but would not be the case if traditional cruising yachts were assessed by the same formula. The method involves the addition and subtractions of the various estimations which is likely to result in a substantial percentage error in the result when this is close to zero, and so is not suited to the assessment of cruising yachts. Furthermore its use is restricted to yachts with IOR rating certificates.

6.2 CHS Screening System

The RORC introduced a more complex system known as the Stability and Safety Screening Calculation Scheme (SSSCS) to their Channel Handicap System.

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 draining 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. FBS = 3.15 L + 0.25 (where L is in metres).

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 and 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 the IOR's SV, but none incorporate the beam/draught or beam/depth ratio, which research has highlighted as fundamental to good large angle stability.

Some of the factors have an effect with doubtful validity. The beam/displacement factor for example (FBD) penalises a yacht with particularly 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 up and sail efficiently. Whilst the initial stability (GM) may be low, this only affects the amount of sail that can be carried and certainly does not prejudice the range. In fact narrow yachts, because of their high ballast ratios, usually have excellent ranges of stability and should certainly not be penalised.

The values assigned to the various factors and the levels of credit given are inevitably subjective. For instance

FR = 1.1 for twin masted rigs
FR = 1.05 for cutter rigs
FR = 1.0 for other rigs.
For masthead rigs add 0.015 to FR.

Thus a cutter is apparently 5% safer, a ketch 10% safer, and a masthead rig 1.5% safer than a fractional rig.

The system addresses a number of features which may affect survival in addition to the stability aspects, and it is complicated, with many formulae, upper and lower limits on the various factors and frequent switching between formulae depending upon the value of certain parameters. This makes the system difficult to interpret, and unsuitable for any vessel without a rating certificate.

As operated by the racing authorities, races are assigned a category depending upon the degree of shelter which the proposed course offers, and all yachts entering a race must have SSS numerals above the limiting value for that race category. The limiting values were allocated subjectively by the RORC, by investigating a number of yachts and, with regard to a general feel for their seaworthiness, dividing them into broad groups appropriate to each category.

6.3 The USYRU/SNAME Screening Value

These organisations appointed a joint committee to investigate yacht capsizing. In their report, Ref. 2, they suggest the simple screening formula:

Screening value = Max. Beam/Cube Root of Displaced Volume

and suggested that its value should be less than 2 for yachts taking part in category 1 (offshore) races.

Prior to the development of this formula the committee had derived the concept of a capsize length as a measure of a boat's size in terms of its resistance to capsize. They proposed the formula:

$$L' = \frac{LI}{I_B}\sqrt{\left(\frac{B_B}{B}\right)^2 + \left(\frac{C_B}{C}\right)^2}$$

where L' = capsize length
L = measured length
I = estimated roll moment of inertia
I_B = base roll moment of inertia = $0.135\ L^{4.5}$
B_B = base beam = L/4 + 2

B	=	measured beam
C_B	=	base centre of pressure above VCG = 2
C	=	estimated centre of pressure above VCG = 2 - VCG
VCG	=	height of centre of gravity above the waterline

These parameters have the units feet and pounds.

For a 'base boat' therefore, the capsize length is equal to its physical length. For a boat with relatively high inertia, narrow beam or high VCG, the capsize length will increase. In the case of the VCG term this may seem strange but in fact a high VCG does provide an increase in capsize resistance, during the few moments of the breaking wave strike. The yacht is then rotated by the impact because that impact is centred above the centre of gravity. If the centre of gravity was at the same height as the centre of pressure of the impact the yacht would be thrust sideways with no rotation. It is after this initial strike that VCG becomes important by governing the stability of the yacht, and whether it will become inverted or return to upright. The capsize length was used to determine the required range of stability of a yacht via the formula:

Minimum range = 160 - L'.

with the proviso that it should not be less than 120 degrees. Hence the range required depends upon length, beam, inertia and VCG.

By plotting values of screening value against the margin of range of stability over the minimum range of 160 - L' for a fleet of racing yachts, a trend was established and the margin was found to reduce to zero when screening value = 2.

The validity of the screening value can not accurately be checked for the yachts in the Wolfson Unit's files because insufficient data are available for a reliable estimate of their inertia. The Americans suggest that the roll inertia may be estimated by

$$\text{Displacement}^{1.744}/35.5$$

(units are pounds and feet). This estimate for inertia was derived empirically by first estimating the inertia of the USYRU racing fleet from data on their rating certificates combined with estimates for rig weight etc. depending on whether the yacht was a 'heavy', 'medium' or 'grand prix' racing yacht. Plotted against displacement on a log scale these values fell on a straight line. The system is therefore based on a number of estimates and assumptions which are not readily verified.

There are some aspects of the capsize length formula which might give rise to a breakdown of the system with size, such as the assumption that the centre of pressure of a breaking wave strike is always two feet above the waterline. The equation of I_B and the estimate for I result in the ratio LI/I_B having dimensions of $L^{1.73}$ and this will contribute to relatively high capsize lengths for large yachts.

These non-dimensional aspects may be illustrated by the use of two vessels geometrically similar but of different size. Whilst the LWL may be increased by a factor of 2 the value of L' may rise by a factor of 5 or more.

It is considered likely that, if actual values of inertia were determined for a fleet of yachts, the data would reveal more scatter than that using estimated values. Since the methods of estimation use basic size parameters it is inevitable that more variation would be introduced by the varying rig weights, construction and internal arrangements of the yachts. In practice this might not have a significant effect on the overall application of the system, particularly to a fleet of similar racing yachts, but it would be a source of concern over the application of the method to a varied fleet of cruising yachts.

6.4 Proposed Wolfson Unit Method

In order to enable small sail training yachts with good stability characteristics to avoid the expense of stability booklet submission, a method was required of estimating the range of stability and screening out those which were undoubtedly satisfactory.

The screening value proposed for Department of Transport use with sail training yachts was

$Beam^2$/(Ballast Ratio x Draught of Canoe Body x Displaced Volume $^{1/3}$)

or $SV = B^2/(R\ T\ V^{1/3})$

and this was developed in the following way.

The range of stability, the ratio of positive to negative areas under the GZ curves, and the difference between these areas were plotted against numerous combinations of yacht dimensions in the search for consistent trends.

The use of areas under the GZ curves revealed such large amounts of scatter that the data could not be condensed into a usable trend, despite the use of such parameters as coachroof volume. Attention was therefore focused on the range of stability.

It was known that the range is dependant to a large extent on the ratio of beam/draught of the canoe body, and this ratio when plotted against range, revealed a strong trend. There were several examples lying well outside the main envelope of data however, and so other parameters were tried. These included depth, length, volume of displacement, coachroof volume, and waterline beam, in various ratios and to various powers.

Bearing in mind the fact that stability derived from high water plane inertia, that is a high BM, is detrimental in terms of resistance to capsize by a wave, the ratio beam squared/draught of the canoe body was considered as a likely component for a successful screening value. This ratio is derived from the formula:

$$BM \quad = \quad I/V = \text{Waterplane inertia/Volume of displacement}$$

I is proportional to LB^3
and V is proportional to LBT where T is the draught of the canoe body.
Hence BM is proportional to B^2/T

This value was non-dimensionalized by dividing by the cube root of volume and, alternatively by length. In order to use the value to estimate the range of stability, a parameter was required which would incorporate the effects of centre of gravity. Since the object of this exercise was to remove the need for inclining some vessels, the only measure readily available would be the ballast ratio. Thus two possible screening values were derived:

$$B^2/(R\ T\ L) \quad \text{and} \quad B^2/(R\ T\ V^{1/3})$$

Where R is the ratio of ballast contained in the keel (not in the bilge) to the yacht's displacement.

In calculating these values, beam overall was used since when heeled to large angles this is the value with most relevance.

Draught of the canoe body is important as it influences the shape of the GZ curve at angles of heel around 90 degrees. For a traditional long keeled yacht with a deep bilge, the value was derived by extending a tangent to the maximum section, at the point of inflexion, and its intersection with the centreline was taken to be the bottom of the canoe body. Draught, volume of displacement and ballast ratio were all referred to the condition of the yacht at the time of inclining.

These two ratios were therefore intended as a measure of a yacht's susceptibility to capsize by a breaking wave. When plotted against the range of stability for the sample yachts they gave an obvious trend with few points outside the main envelope. The use of volume in the ratio rather than length gave a particularly promising result, the remaining scatter of the data being due to several factors. In the screening formula the hull's detailed shape, the coachroof volume and the location of the ballast have not been considered. Furthermore, the stability range of two yachts from the same mould may be different because of different internal configurations giving rise to different VCG locations. The scatter in range is greater at low screening values, where the range is large. This is inevitable because with a large range of stability the GZ curve intersects the axis at an acute angle, and small changes in yacht geometry result in large changes to the range.

Figure 3
Variation of range with Wolfson Unit screening value. The lines shown are those used to estimate range from screening value.

A minor modification was adopted in the Code of Practice. The value of the draught of the canoe body was altered to be the draught at a distance of B/8 from the centreline. It was thought that this was a more precise definition, less open to varied interpretation, and it is this value which has been used to calculate the screening values plotted in Figure 3.

By fitting a line through the available data, the formula enables a prediction of the range of stability for any yacht for which design data on ballast weight and displacement are available. The line may of course be moved to provide a conservative estimate if desired, to allow for growth of the yacht over the designer's estimates, and for discrepancies between the ballast weight quoted and that actually installed. The line chosen was a hyperbola drawn through those vessels with the lowest range for their screening value. This was the line proposed for use by the Department of Transport, since it would result in an estimated range which would be unlikely to exceed the actual range. This method assumes that the sample yachts used include those with the lowest possible range for their screening value. This will obviously not be the case but it is considered unlikely that other vessels would fall below this line by a significant margin. As more data become available in the future the proposed formula may of course be adjusted if necessary to give a lower prediction.

The proposal met with strong criticism from representatives of the sail training industry however, and a revised line, also shown on Figure 3, was adopted in the Code of Practice. It generally gives a more accurate estimate of the range of stability, but of course in some instances it is known to over-estimate the range. This has resulted in the anomaly that a yacht which would just fail to meet the range requirement if examined accurately, could perhaps now be approved on the basis of its estimated range.

The formulae which correspond to these lines are:

Wolfson Unit proposal: Range = 110 + 290/(SV-6.7)
Adopted formula: Range = 110 + 400/(SV-10)

6.5 STOPS Method

The RORC and RYA proposed a modified form of the SSS scheme described in 6.2 for use with sailing school yachts. To make the system more attractive to the Department of Transport a further factor was incorporated, known as the vanishing angle factor. This is derived by first calculating the estimated range using the procedure described in 6.4. The estimated range is divided by the required range for the category of operation, and the result is cubed.

A limit of 1.25 is placed on this factor so maximum credit is given for an estimated range 7.7% above the required range. The adopted formula for estimated range may over-estimate its value by considerably more than that, possibly giving maximum credit to a yacht whose true range would not meet the minimum requirement.

A listing of the computer program used to calculate the STOPS numeral is presented in Appendix I, and the relative merits assigned to various features can be found within it.

Since not all of the sailing school yachts have IOR rating certificates the factor FSR, using the inclining experiment data, is not included. For yachts with an IOR certificate the SSSCS number is used in place of the STOPS numeral to assign a category.

The numerals thus obtained are compared with minimum values required for operation in the various regional categories. The magnitudes of the limiting values were selected subjectively by the RYA and RORC, in a similar way to the allocation of SSS limits for race categories. Unlike the range estimate method, or indeed the accurate assessment, the STOPS method differentiates between categories 0 and 1 in the magnitude of the numeral required.

7. EXPERIENCE WITH USE OF APPROXIMATE METHODS

Since the DTp's Code of Practice was introduced, most of the UK registered sailing school yachts have been certificated by the RYA, one of the certifying authorities appointed by the DTp. Their database contains over 250 yachts, although there are multiple examples in the more popular classes.

All the permitted methods of assessment are represented in the database: some have IOR certificates and are certificated on the basis of their SSS numeral, some meet the requirements on the basis of their estimated range, some have been assigned STOPS numerals and for some there has been a conventional assessment with an inclining experiment.

It is interesting to note that only three of the yachts (1%) have had to be inclined because they failed to meet the requirements of the desired category on the basis of the approximate methods.

Figure 4 indicates the spread of data across the categories, which would have resulted using the original screening method proposed by the Wolfson Unit. Many of the yachts fail to meet the requirements for even the coastal category and so a large number would need to be inclined to examine their stability and justify their suitability for sail training.

Figure 4
Category allocation using the original screening method proposed by the Wolfson Unit.

Figure 5
Category allocation using the adopted range estimate method

Figure 5 shows the same data with the range estimated using the adopted method. Eleven of the yachts now have an estimated range of 180 degrees and few fail to meet the requirement of category 3.

Of the 170 yachts used in these figures, only 154 have had STOPS numerals calculated so a comparison of the full sample is not possible, but for the 154 yachts for which STOPS and range estimate data are available, a comparison of the assigned categories is presented in Figure 6. These bar graphs indicate the percentage of the sample put in each category by three of the methods. 45% would fail to meet the requirements of category 3 if the original method proposed by the Wolfson Unit were used and only 8% would be able to operate in category 0. With the adopted range estimate method only 10% fail to be assigned a category and with the STOPS method none of the 154 yachts falls below the minimum requirements for category 3.

Figure 6
Number of Sailing School Yachts Placed in Each Regional Category by Different methods.
Total Number of yachts = 154

The two smallest yachts in this database provide an interesting comparison. Their principal dimensions are presented in Table 1.

Table 1

LOA	Beam	Draught @ B/8	Displacement	Ballast	SV	Estimated Range	STOPS
m	m	m	tonnes	tonnes		degrees	
8.0	2.8	0.3	2.57	0.63	78.5	116	21
7.9	2.2	0.5	2.65	1.24	15.1	180	28

The first, with its wide beam, shallow hull and ballast ratio of 25% will have a low range of stability. It would not be granted a certificate on the basis of its estimated range but its STOPS numeral puts it in category 3. The second has low beam and a ballast ratio of 47%. Although it may not have a range of 180 degrees, its range will be sufficient to make it effectively self righting and it is a form which is less vulnerable to breaking wave capsize than the other. Its STOPS numeral of 28 puts it in category 3 also, whilst on the basis of estimated range it can operate in category 0.

In the RYA database there are 66 yachts which have been assigned a category on the basis of a SSSCS numeral derived from their IOR rating certificate 16 (24%) of these are in categories 0 and 1, and 50 (76%) in category 2. None of the yachts are placed in category 3 or below. 21 yachts have had accurate GZ curves produced and of these one is in category 0 and the remainder are in category 2.

These statistics show that yachts with IOR certificates are likely to be assigned a sufficiently extensive category for sailing school operations. Other yachts can first be tested against the simple range estimate method and if that fails to permit operation in the desired category the STOPS method will be used. The yachts which have been inclined have apparently been examined at the request of the designer or builder rather than as a means of assessing the stability of marginal cases, since none of them fall in or below category 3.

The conclusion to be drawn from these statistics is either that all sailing school yachts have stability characteristics which are beyond question, or that the approximate methods being applied are not sufficiently stringent to force the operators of the marginal ones to undertake an accurate assessment.

It was hoped by the Wolfson Unit that it would be those yachts of traditional narrow form and high ballast ratio, which are represented by the diagonal group which fall in category 0 of Figure 2, that would be granted certificates without recourse to a full assessment. Figure 5 indicates, albeit on the basis of estimated ranges, that the majority of sailing school yachts fall in the same region as the rating rule influenced yachts of Figure 2, with lengths of 8 to 12 metres and stability ranges of 120 to 140 degrees. These are the types of yacht which were considered marginal yet they are not being rigorously tested.

Thus the philosophy behind the introduction of approximate methods, that is as a screening system for the most stable yachts, appears not to be working in practice, since no marginal yachts have been inclined and indeed only 3 yachts have been inclined as a means of moving up a category from that allocated by approximate methods.

The 170 yachts which appear on Figures 4 and 5 were tested with the USYRU screening value and this would permit 66% of the yachts to sail in their offshore races.

8. VARIATIONS OF STABILITY WITHIN A CLASS

During discussions on the adoption of approximate methods by the Code of Practice, the Wolfson Unit's proposal was heavily criticised by those favouring the STOPS method, because its formulation included ballast ratio. Apparently this is a notoriously unreliable figure quoted by designers and builders, the actual ballast cast often being somewhat less than that requested. If this is truly the case then no approximate assessment of the stability can ever be expected to succeed since large angle stability depends to a great extent on the centre of gravity location. If a designer does not know the exact ballast weight, neither he, nor the authorities, can be sure of the stability without inclining the yacht. It is therefore important that an approximate method has sufficient safety margin incorporated to allow for such unknowns.

In comparison with commercial vessels for which stability regulations have been developed, a yacht is very small and its components each have a significant effect on its stability. The fitting of a radar scanner for example would have negligible affect on a coaster but might reduce the range of stability of a yacht by several degrees.

When using an approximate method therefore, it is important that the surveyor notes any features of the arrangement and outfit of the yacht which deviate from that intended by the designer.

Figure 7
Stability curves for two yachts of the same class with different rigs.

Figure 7 presents stability curves for two examples of a class of 8.7 metre production cruising yacht. Using the adopted range estimate method this class has an estimated range of 120 degrees. The yacht with a range of 127 degrees has a conventional rig as designed, the other with a range of only 96 degrees, has a mast furling mainsail and a roller furling headsail fitted. The additional weight aloft on this yacht has thus reduced its range by 31 degrees.

There will always be variation of stability within a class but in general the differences will be much less than in the above example. The data shown in Figure 2 include six yachts of 22 metres, all constructed to the same basic design, and operated by the Ocean Youth Club. Their range of stability varies between 119 and 126 degrees, with no single yacht standing out as being notably different from the others. The variations being the result of minor differences in the arrangement and perhaps variable growth over their period of operation of 15 to 20 years.

Figure 8

Stability curves for six Contessa 32's

Figure 8 also illustrates variation within a class, this time the well publicised Contessa 32. The displacements and centres of gravity for yachts 1 to 5 were derived from inclining experiments performed as part of the IOR rating procedure, yacht 6 was inclined, using the conventional method, by a DTp Surveyor. Yacht 1 is raced competitively by its owner and presumably excess gear is kept to a minimum. Yachts 2 and 3 are operated by sailing schools and will contain little in the way of personal belongings. Yachts 4 and 5 are cruised and raced by private owners. Yacht 6 is cruised only, and presumably contains the accumulated gear typical of a family cruising yacht of several years service. Its displacement is 27% greater than that of Yacht 1.

The Code of Practice requires yachts of over 15 metres to be marked with the minimum freeboard for which the stability has been approved. No such requirement exists for smaller yachts but the above example reveals the growth which can occur and its effect on stability. The Contessa's range puts it well above the minimum requirement for category 0 but in another class such variation might span the minimum and a yacht which meets the requirements when delivered, might not do so after a period of operation and growth. If an authority does not intend to check on growth, it should therefore set the minimum requirements with due regard to the possible effects and incorporate an appropriate margin.

9. CONCLUSION

With substantial variations in stability characteristics resulting from differences in the arrangements of yachts and variable growth, the only way to assess their stability with confidence is carefully to conduct an inclining experiment and calculate the GZ curve.

Approximate methods must be regarded as such and, if stability limits are to be imposed, the authorities must be confident that those methods do not provide loopholes or over-optimistic assessments. In order to ensure this the approximate methods need to err on the side of safety or, alternatively, the required minimum values must be set with a suitable margin of safety to allow for the inaccuracies.

If it is agreed that the range of stability limits incorporated in the Code of Practice are appropriate for the various categories; it appears that the approximate methods are enabling many yachts with marginal stability characteristics to operate without sufficient investigation.

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2. 'Final Report on Safety from Capsizing.' United States Yacht Racing Union and SNAME 1985

3. 'The Safety of Sail Training Ships - A Code of Practice'. The Department of Transport Marine Directorate, 1990.

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

APPENDIX 1 - STOPS Program Listing.

Extracted from Ref. 3.

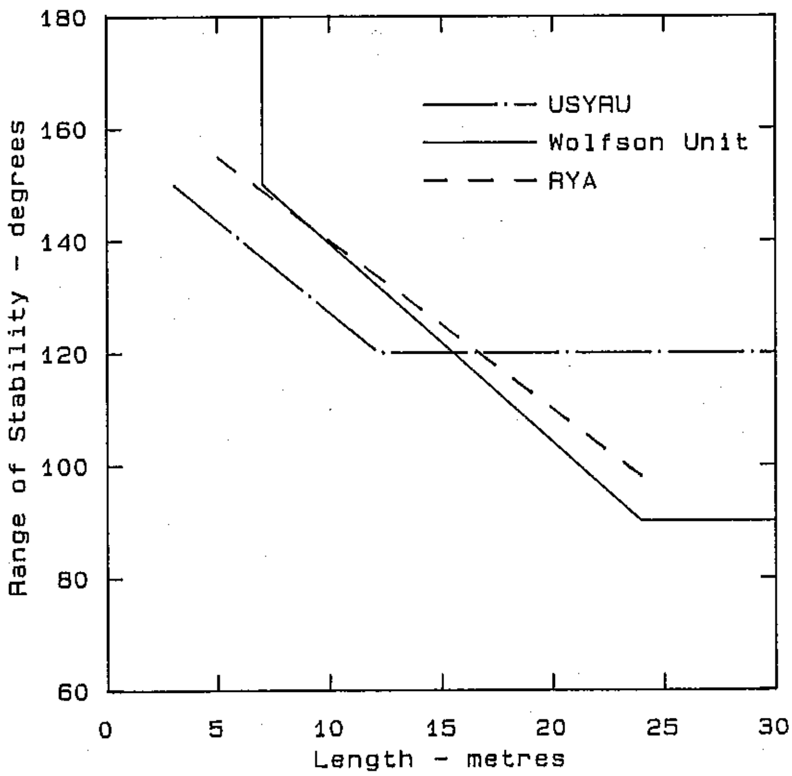

Figure 1
Three proposals for minimum range of stability

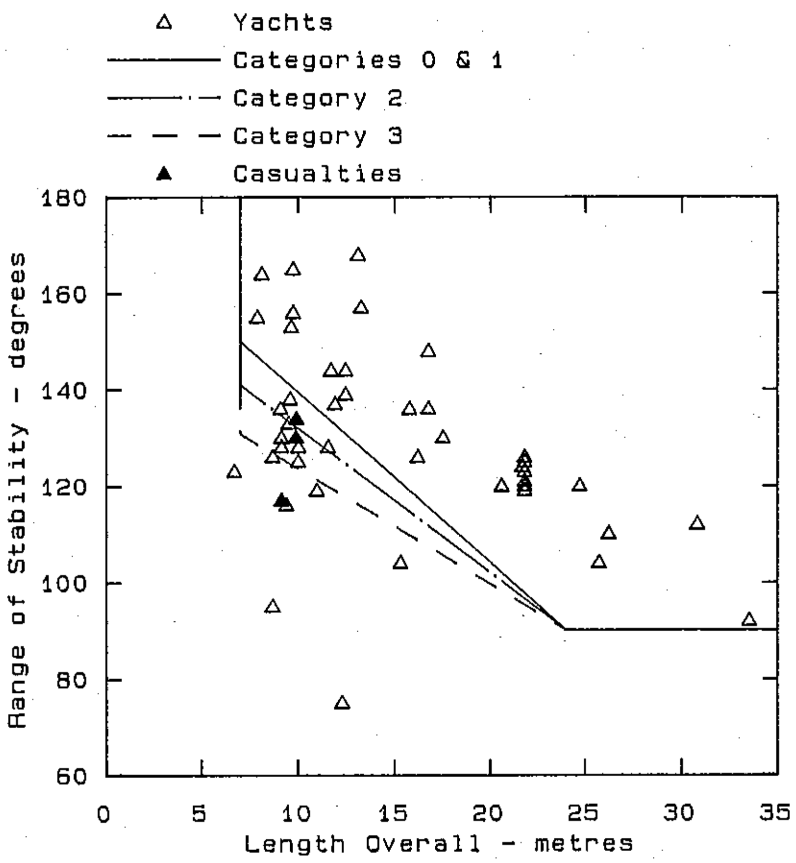

Figure 2
Minimum range of stability required by the Code of practice for each regional category.
The yachts are those for which the wolfson unit has reliable inclining experiment data

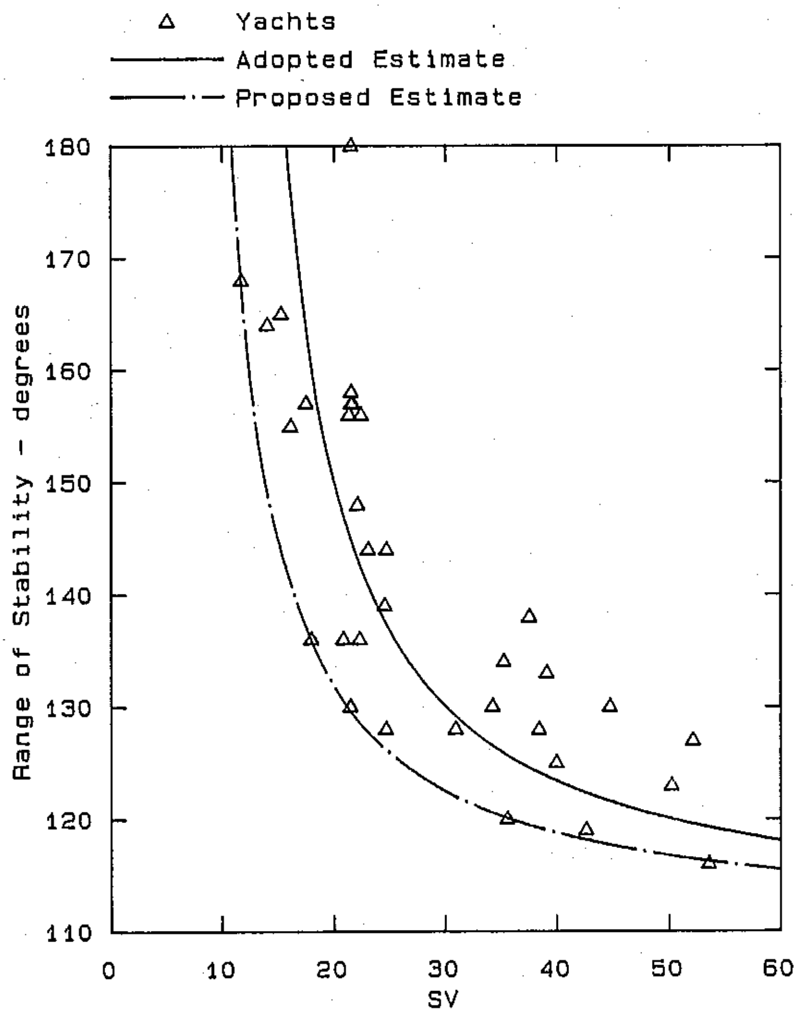

Figure 3
Variation of range with Wolfson Unit screening value. The lines shown are those used to estimate range from screening value

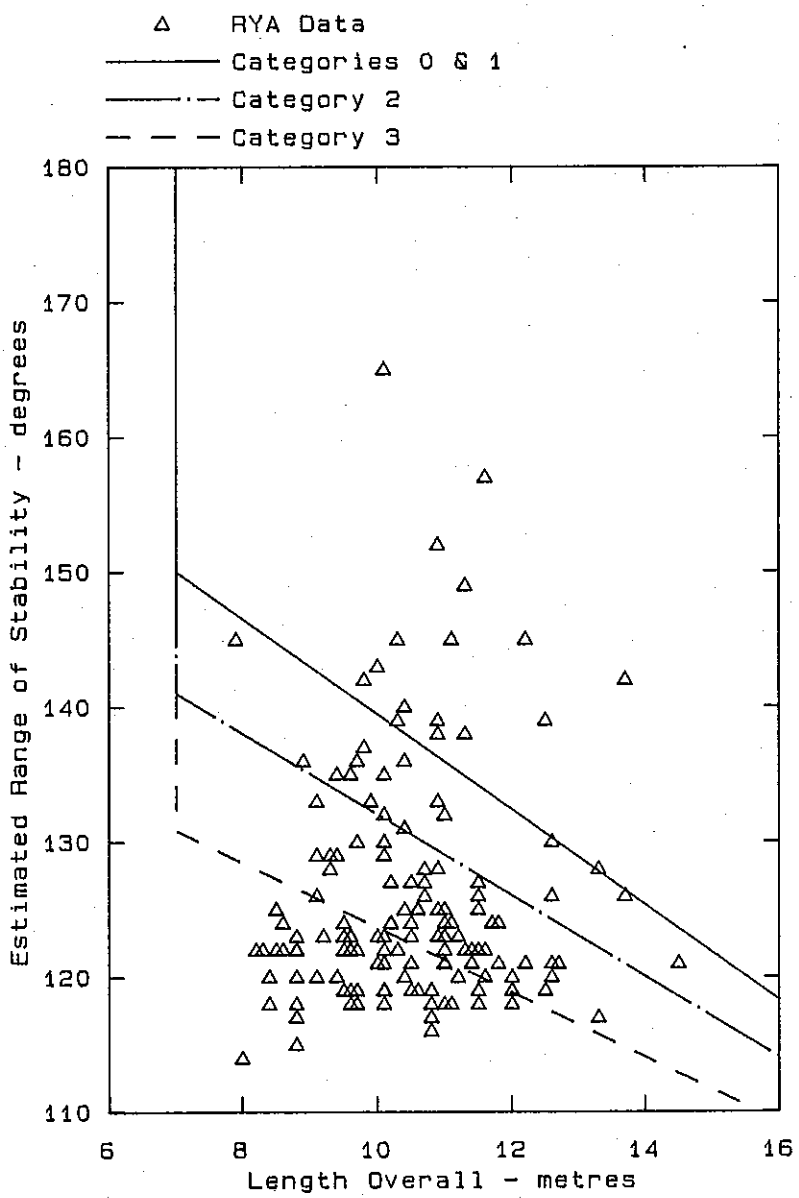

Figure 4
Category allocation using the original screening method proposed by the Wolfson Unit

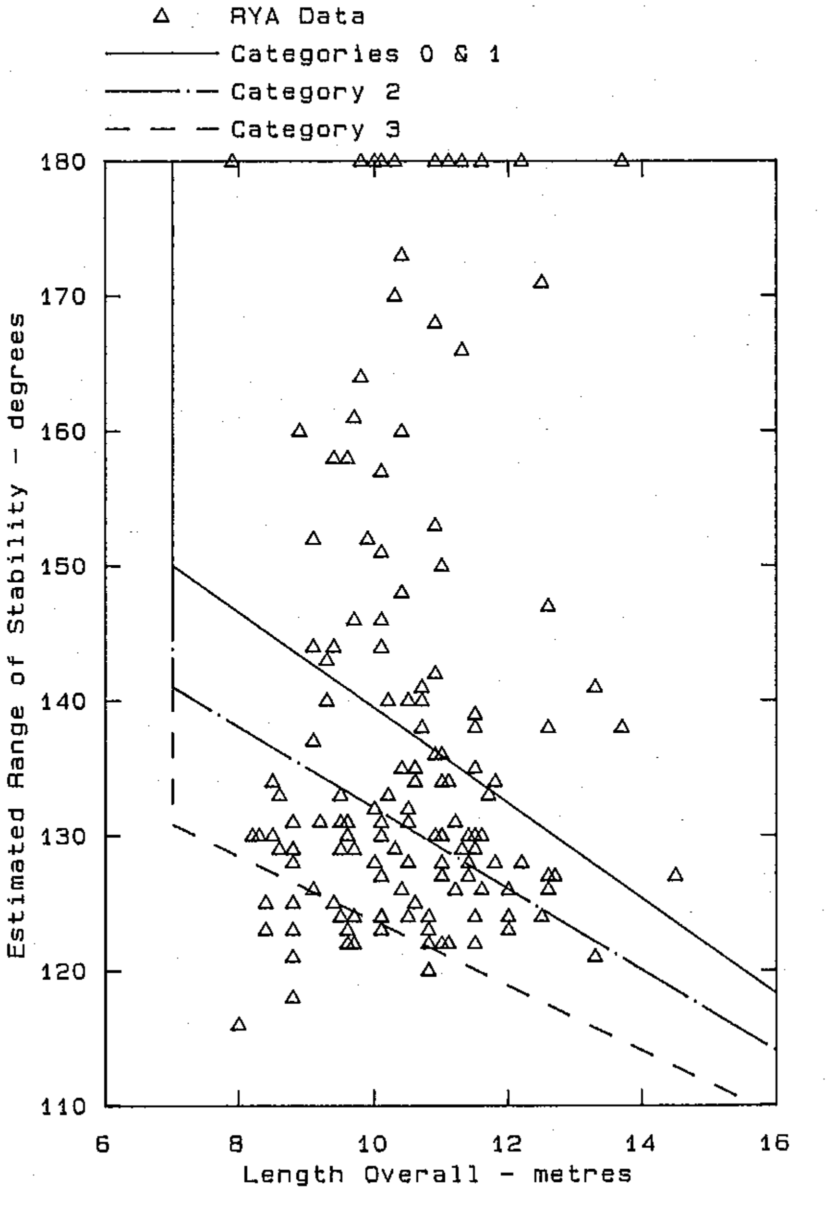

Figure 5
Category Allocation Using the Adopted Range Estimate Method

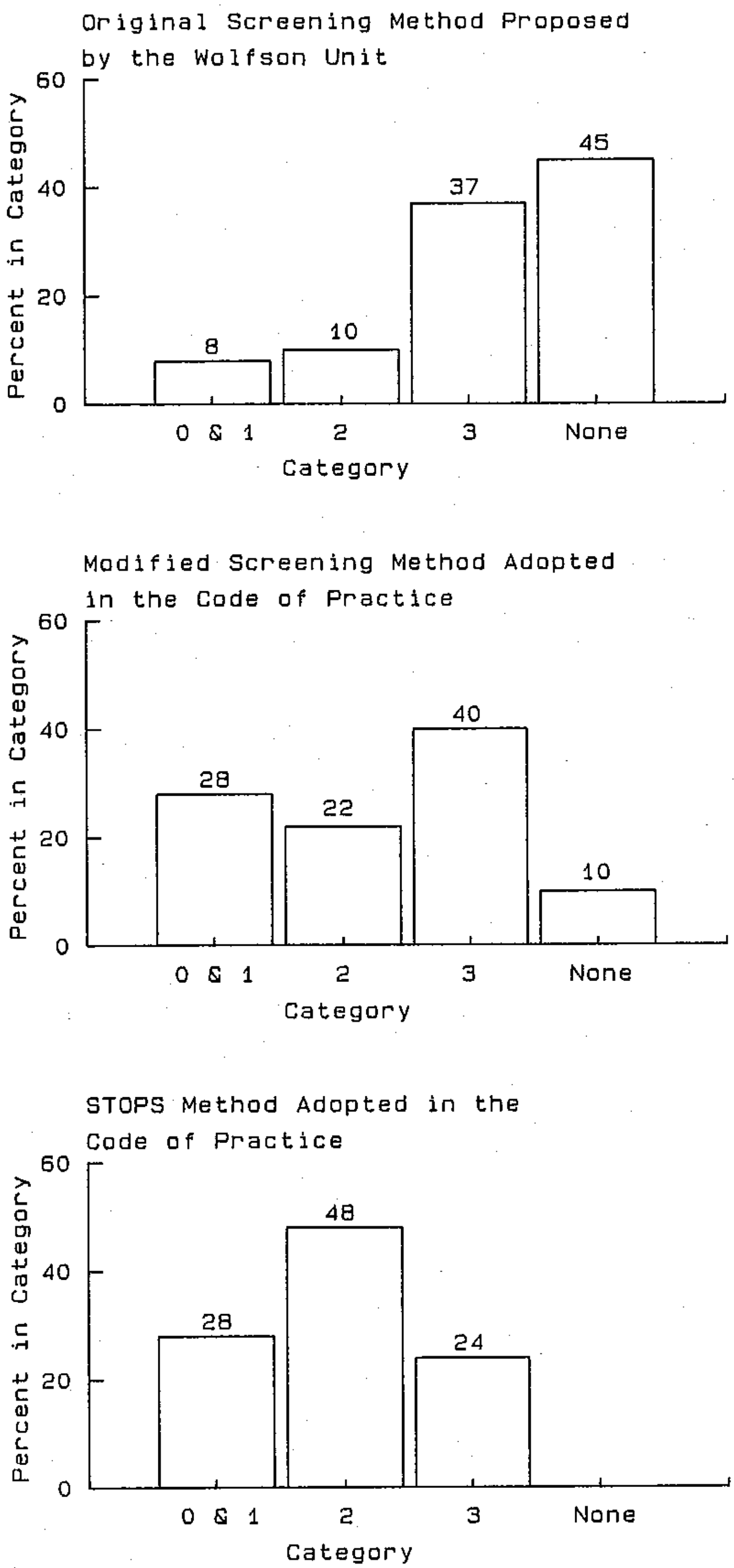

Figure 6
Number of Sailing School Yachts Placed
in Each Regional Category by Different Methods
Total number of yachts = 154

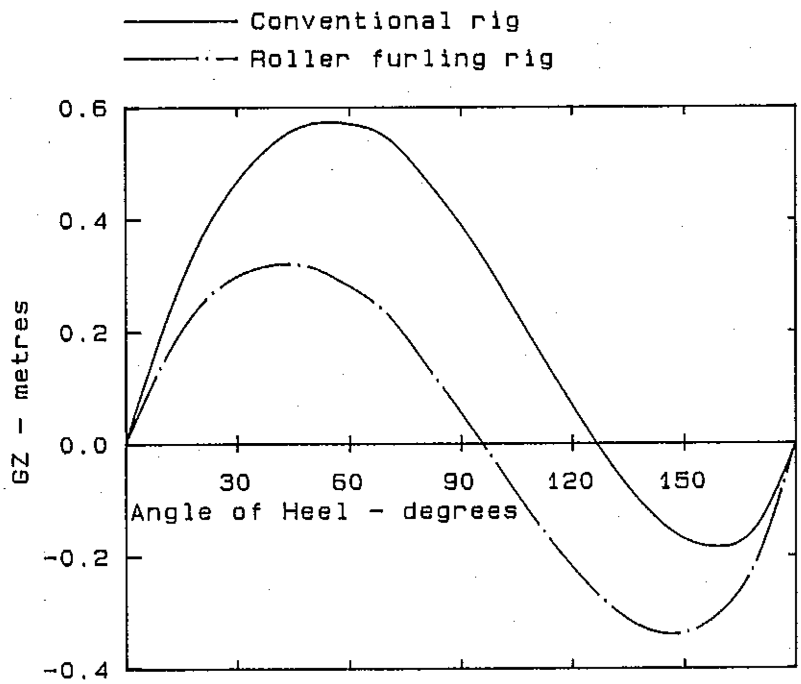

Figure 7
Stability curves for two yachts of the same class with different rigs

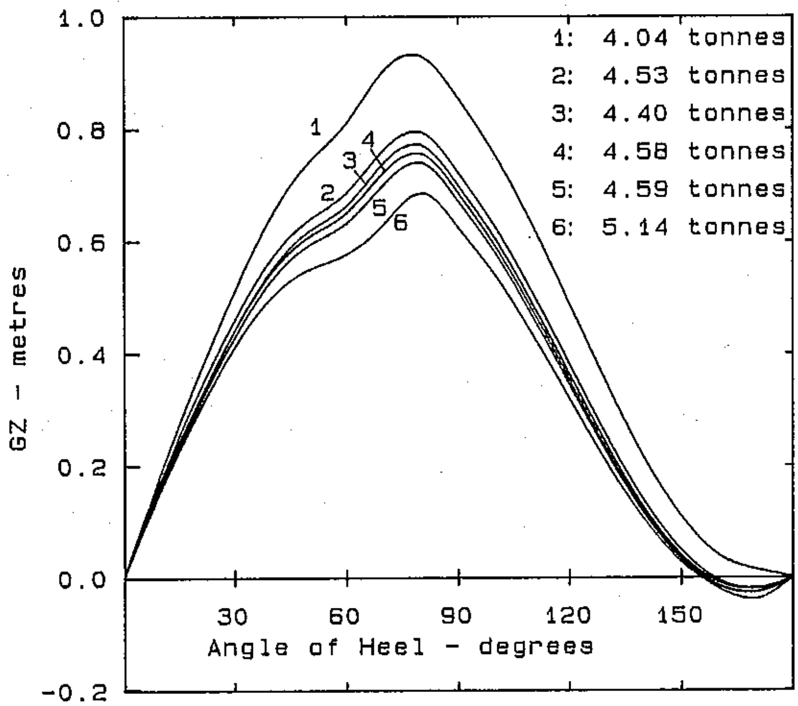

Figure 8
Stability curves for six Contessa 32's