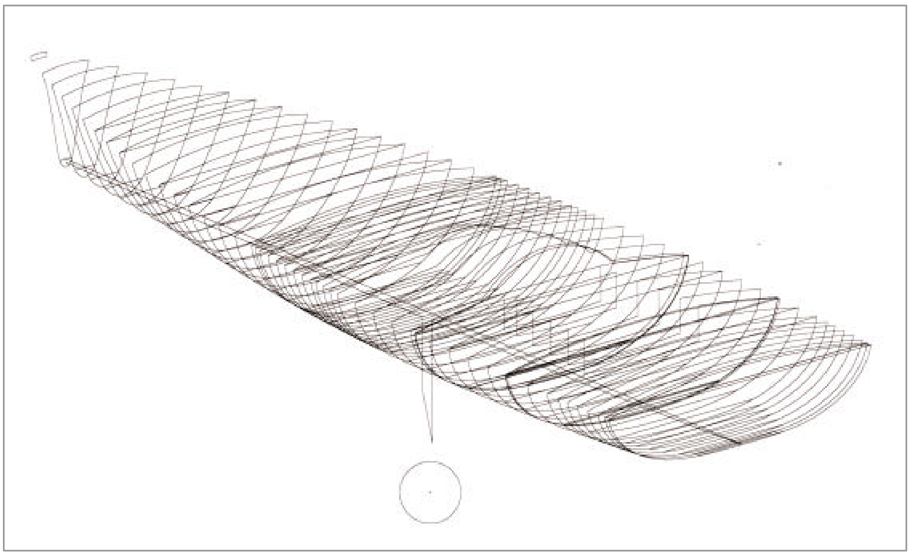
Stability of 60' and 50' Open Monohulls

By Jean Sans - 17 January 2000
Translate by Simon Forbes

This paper has been based on a numeric model of an Open 60, this model is not representative of all Open 60's, but it possesses the characteristics that one finds on this type of boat.

There exists amongst the 60' fleet, boats with better stability characteristics; there exist also boats that have stability criteria inferior to those described in this paper.

This study of stability is based on a yacht complying with Appendix 1 of the FICO regulations, the condition a boat would be in at the start of a race. The purpose of this paper is to contribute to the understanding of this type of boat.



<u>Stability of 60’ & 50’ Open Monohulls</u>

Different meetings of FICO have assembled competitors, organisers, race committees during the last years and principally since the capsizes of the last Vendée-Globe ('96-'97). Certain technical decisions to limit the risk of capsize of the 50’ and 60’ open monohulls were made.

We should pose the question why only these monohulls are concerned with the risks of capsize. We should be conscious that until 1998 the ORC Regulations required that monohulls should be “self-righting” and close to the whole world thought that this was the case for an offshore boat. We had found that the Vendée-Globe[1] runs in the direction of generally following winds (the shape of the boats would have been very different if the course were to be reversed) which is what caused the architects to develop the hull forms and deck very optimised for speed at the detriment of the overall stability of the boat. Other boats racing fully crewed on the same course, but with rules that imposed minimum stability requirements, limited the architectural diversions.

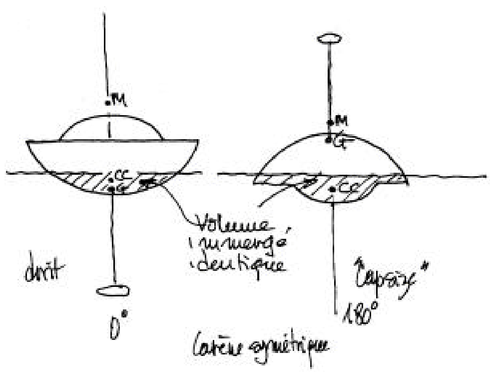
Finally to well understand the stability of yachts and these “Open” yachts it is necessary to do a little physics without exploding the neurones.

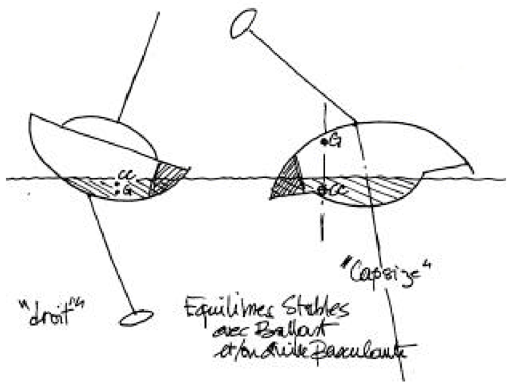
<u>A – Starting With Equilibrium Positions of Yachts</u>

1/Stable Equilibrium of a boat

A boat possesses two stable equilibrium positions, one with the mast in the air, the other with the keel in the air.

When the boat is displaced from one of these two positions of equilibrium by a mechanical means (wind, sea, etc) it tries to return to its original position if the force is slackened. If the boat is balanced or is equipped with a pivoting keel, trimmed to one side, it finds in the same manner two stable equilibrium positions, several° from the vertical (around 10° with the mast in the air, 15 degree with the boat capsized – approximate value depending on the design of the boat.





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[1] Vendée-Globe is a single-hand race around world (one leg)

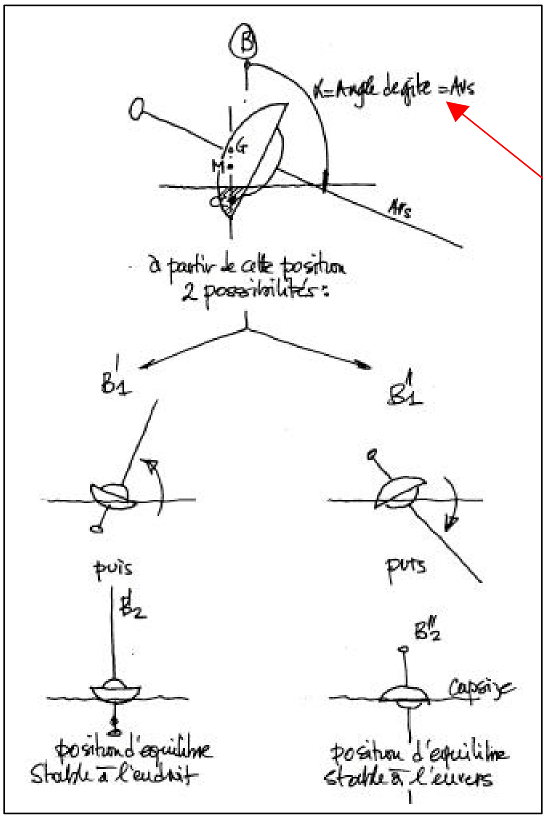
2/ Why this Equilibrium?

Simply because the centre of gravity of the boat (distribution of masses in the space) and the centre of buoyancy of the immerged volume are on the same vertical line and that the metacentre is found above the centre of gravity. We must not lose sight that whatever the position of the boat (angle of heel and any trim), the weight of the boat and its centre of gravity are fixed. It is not the same for the centre of buoyancy, because if the immerged volume does not vary, on the contrary the shape of the immerged volume is different for each angle of heel and trim. This infers that the centre of buoyancy changes its position in space for each variation in position of the boat.

For a boat without ballast and with a fixed keel, the centre of gravity is obligatory in the plan of symmetry of the boat (one neglects the lateral displacement of crew, and the boom etc) when a ballast tank is filled up, or when the keel is cranked up on one side where the ballast or keel is " active".

For a 60' or 50' Open Monohull the centre of gravity is situated around the bottom of the hull – that is around 300 –350mm from the water line

3/Unstable Equilibrium

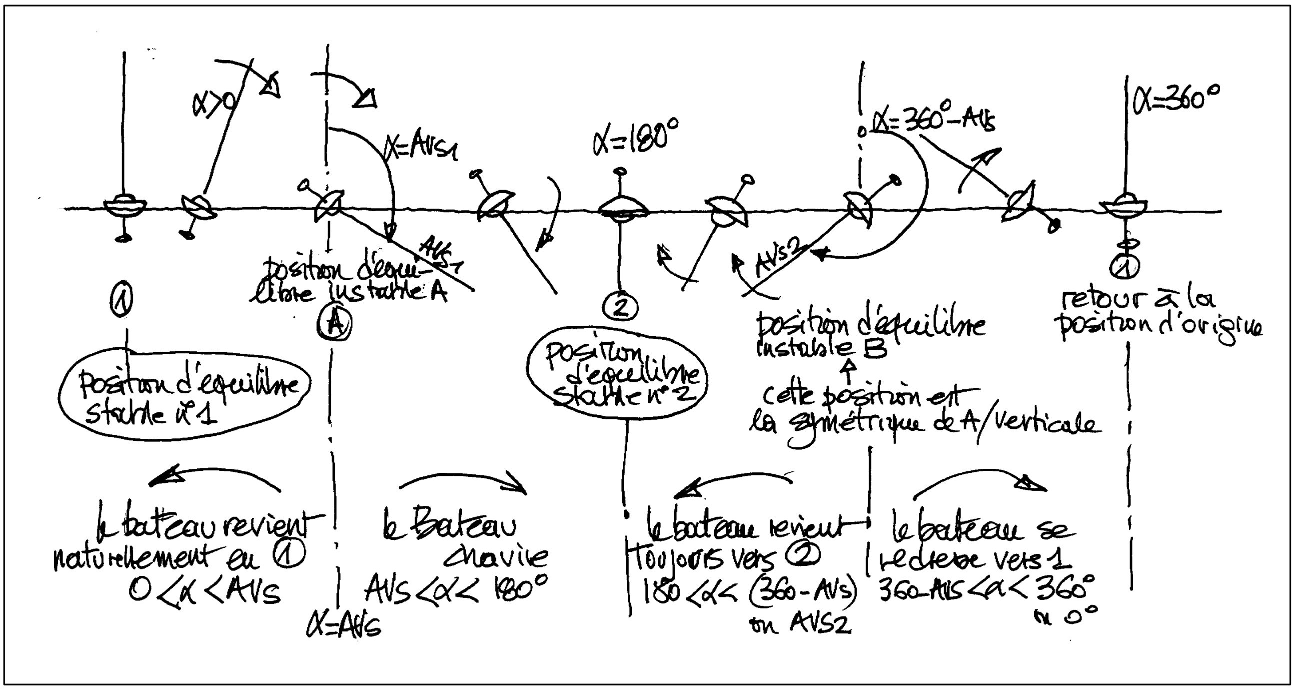


There also exists two unstable positions. The two positions are characterised by that when the boat attains these positions, one does not know which side the boat will pivot to reach one of the two equilibrium positions (Fig. 1)

When we have an equilibrium position, the centre of gravity and the centre of buoyancy are on the same vertical plane, but the instability is due to the metacentre being below the centre of gravity (difference with stable equilibrium). The angle of heel corresponding to this <u>position of unstable equilibrium is called the AVS</u>. Remember again this position of unstable equilibrium corresponds to the moment where on a dinghy one starts to re-right the dinghy or put the mast underneath.

When one talks of two positions of unstable equilibrium, in a symmetrical boat (that's to say without ballast nor pivoting keel or ballast tanks empty and pivoting keel in the centreline) a position to port and a position to starboard. These two positions are identical (same angle) and one talks of angle AVS port and angle AVS starboard. If one takes into account that the boat starts vertical (heel = 0°) and makes a complete turn (360°) the positions of unstable equilibrium are AVS1 and AVS2.

Example: If the angle AVS1 of the first position of equilibrium is 125°, the other angle AVS2 of the second position of equilibrium will be 235°. These two angles represent on one side 125° (AVS1) and on the other side (360-AVS2) = 125° also. One considers that the boat makes a complete 0 – 360 as represented in the synopsis below.



Synopsis between 0° to 360°

4/The Reality

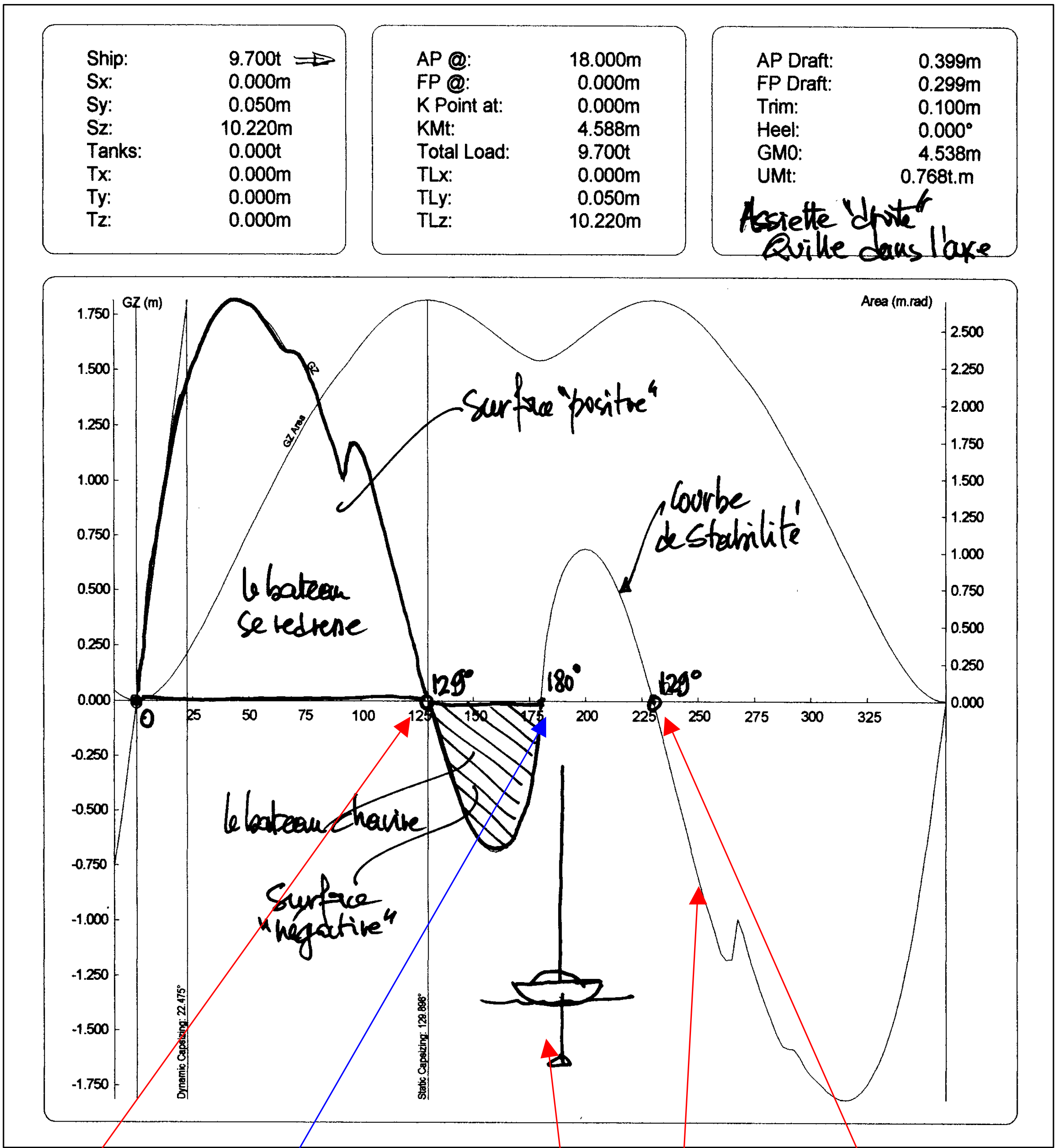
When the boat is under sail it is in total security when the angle of heel is between 0° and the angle AVS1, the part symmetrical is also acceptable, heel comprised of AVS2 and 360°. Diverse mechanical prompts (wind, sea etc) provoke the heel. Studying the stability curve over 360° of a boat with ballast tanks empty and keel fixed (0°). On the axis OY is transferring the couple of righting (>0) or a capsize (<0).

When the boat passes the angle of AVS, it will inexorably capsize, and attain the position “capsize” at 180° (position stable, very stable).

To leave this position and return towards the normal position (0°), the boat will have to find the energy to attain the value of AVS or (360°-AVS). Several dedrees less than AVS or several degrees more than (360°-AVS).

One should be conscious that the boat can be far away from the position “capsized” on one side or the other but without attaining AVS or (360-AVS), it will remain inexorably in the position “capsized”. Therefore the smaller this angular area is the more it is possible to re-right the boat. The smaller the hatched area is, the less energy will be needed to attain AVS or (360-AVS). It is for this reason that FICO[1] has imposed an angle AVS of 125° or (360-125) and a ratio of positive area to negative of the stability curve (for a symmetrical hull) between 0° and 180° of 5/1.

[1] In IMOCA rules, AVS mini=127°5, but without mainsail on the boom or jibs on furlers



AVS *Capzise* *position de départ* *courbe de stabilité* *(**360°-AVS**)*

These two parameters shall be checked in conditions of measurement and calculations as close as possible to that which the boat is in when sailing. This choice is important, a roller furling stay equipped with a genoa – raises the centre of gravity of the boat 20 to 30cm, a mainsail of 200kg also raises the centre of gravity, (the centre of gravity of the mainsail is found 9m above the waterline!).

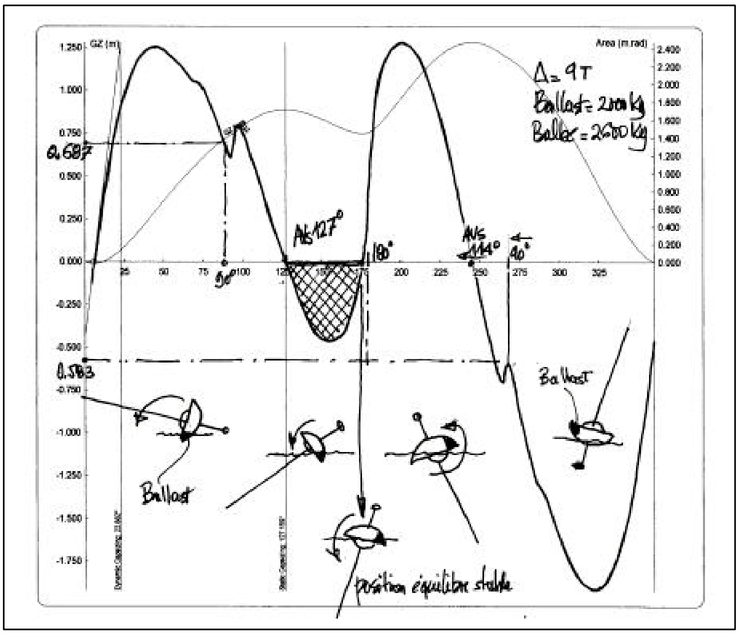
All these elements translate at 90° to a base of righting couple of 10% to 15% of the angle of AVS (around 3 to 7°). It is necessary to go through this angle (and to find the energy to do this) to re-right the boat otherwise it will capsize.
Of course the skippers want to be able to "cheat" and pass the stability test with the lightest sail, with furlers in place of roller reefing headsails. They play an extremely dangerous game, which should be limited by a protocol of draconian requirement.

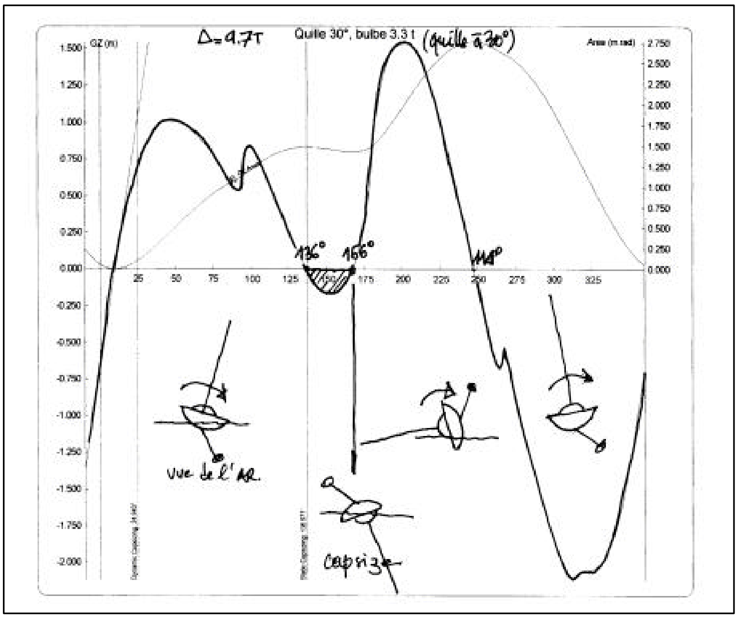
B-Stability and Instability of a boat Equipped with Ballast and/or a moveable Keel.

1/Introduction

We are taking on a complex problem, because if the positions of equilibrium with ballast and keel cranked (understand that the ballast tanks are full and that the keel is cranked at maximum position) we are very similar to those of a normal boats, the results, therefore the general stability is not "perturbed" by the asymmetry of the hull. This asymmetry of the boat (stable equilibrium, mast in air of around 10° on one side) will be considered during all the angles of heel of the boat from 0 to 360°. The effects of the asymmetry are far from negligible contrary to what we often hear. It is for this reason that the rule of 10° of maximum heel under the effects of ballast existing in the FICO regulations should be retained.

2/Synopsis of <<0 to 360°.





The filling of a ballast tank, the cranking of a keel on the same side provoke the boat to heel in a position close to the vertical (max 10° for a 50' to 60' Open monohull). This angle of initial heel represents the starting position.

On making a turn of the boat, rolling as the sailors call it, one finds an identical scenario to that of the synopsis of 0 to 360° in paragraph 3 above, that is.

As one goes along with the angle of heel increasing, one finds the angle where the centre of gravity are on the same vertical, this signifies that the righting couple is zero for this angle (AVS). For (AVS-epsilon), the start of the capsize couple takes form on the inexorable route towards capsize (the position of stable equilibrium upside down)

When one continues the rotation (for the moment, we do not pose the question where does the energy needed to make this rotation come from) we then find another position of unstable equilibrium (AVS2). If we pass this value of AVS2, we can find a righting couple and the boat then returns to the starting position. We have covered 360° of rotation.

The only difference with the synopsis of the symmetrical boat is that the stability curve no longer has a point of symmetry in relation to the corresponding angle of heel with the boat upside down. The total is completely asymmetric.

This signifies:

? That the righting couple and the capsizing couple are not identical in the two zones (zone 1 is from 10° to the position upside down and zone 2 is from the upside down position to 360° + 10°).
? That the angle AVS1 of the zone 1 is not the symmetrical equivalent in zone 2.
? That the surface >0 and <0 are also different.

In studying the curve of stability one appreciates that if the boat pivots on the side where the ballast tanks are full or the keel is cranked:

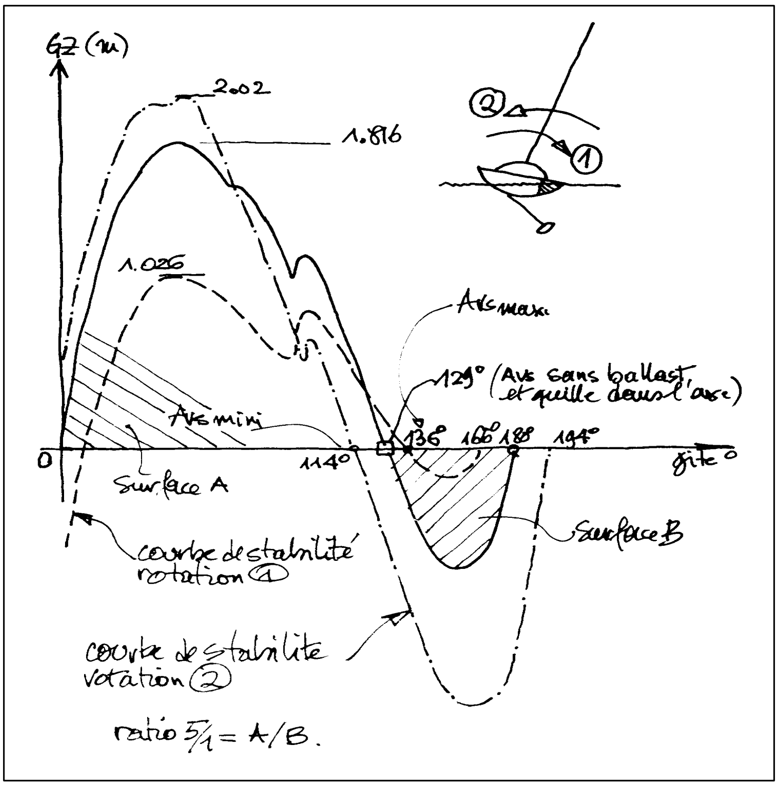
? The boat is less stiff than in the case of a symmetrical hull without full ballast or keel cranked.
? The angle AVS1 is on the other hand bigger than the angle AVS of the same hull without full ballast tanks or keel cranked.
? On the contrary, when one passes the upside down position and one returns towards the "vertical" position, the angle of equilibrium AVS2 is bigger than the equivalent with a symmetrical hull. Attention, this signifies that if one has pivoted the boat in the opposite direction (windward ballast full in the first part of the rotation) the equilibrium position AVS2 will be a value smaller than the angle AVS "normal" but on the counterpart, the righting moment is well increased.

The phenomenon is logical, when the ballast or keel increase the stiffness the boat capsizes earlier on the side opposite the stiffness conversely when the ballast or the keel reduce the stiffness, the boat capsizes later on the side where the ballast is full, as opposed to the case of the weaker righting couple.

The FICO regulations[NOTE] impose as stability criteria the angle of AVS of 125° and the ratio of 5/1. These two criteria are established ballast tanks empty and keel on the centre line. A protocol of measurement and calculations indicate the methodology to follow to obtain the parameters necessary to control these two criteria.
Then the appendix 1 of the FICO rules, proposes a method destined to evaluate the effect of ballast and of a pivoting keel on the general stability of a boat. The method proposed actually required that the GZ 90° with ballast tanks full and keel cranked is less or equal to 75% of the GZ 90° with out ballast and with the keel on the centreline. This parameter is not the only information on the overall stability of the boat. The most favourable angle of AVS gives also useful information because it specifies the angle of heel that will be attained at the beginning of the capsize position, for the boat to re-right. If this angle AVS is greater than 125°, we find ourselves in the configuration "normal" of the boat (without ballast, keel on the centreline and this is satisfactory). In all cases if the FICO regulations is respected (125° and ratio 5/1) it is possible that the angle AVS is greater than 125°. When this

[NOTE] This part of the text (in italic) was written in December 1999 for the Vendée-Globe, since regulation FICO was aligned on IMOCA regulation (IMOCA is an International Class ISAF) *is verified it is the target of annexe 1 and the protocol of measurement associated with it.*

We have planned to obtain the GZ 90° with ballast tanks full and the keel cranked by measuring the force at the top of the mast, as planned when the ballast is empty and the keel is on the centreline. In fact to measure ballast tanks full and the keel cranked is very complex to perform and poses problems of safety at the start of the operation. The control of the influence of ballast tanks and of the cranking the keel will b made starting at GZ 90° or the angle AVS (see in a similar style No.1 of the FICO 99-2000).



<u>C – Re-Righting the boat from Capsize Position</u>

1/Problem to resolve

How a boat in stable equilibrium at 180° “capsize” will return “upright”? (The case of a non-ballasted boat or with the keel on the centreline at the moment of capsize)

The solution is “simple, astonishingly simple” (I do not speak of putting in place the solution): it is sufficient to arrange the boat in the position of unstable equilibrium (AVS) to slightly pass this situation so that the righting couple then becomes positive and that the boat rights itself to return to the “normal” position. It will be necessary to pivot the boat a certain amount to get to this position capsize (180° – AVS). One knows also that if one does not attain the angle of unstable equilibrium (AVS), the boat will return inexorably to the capsize position.

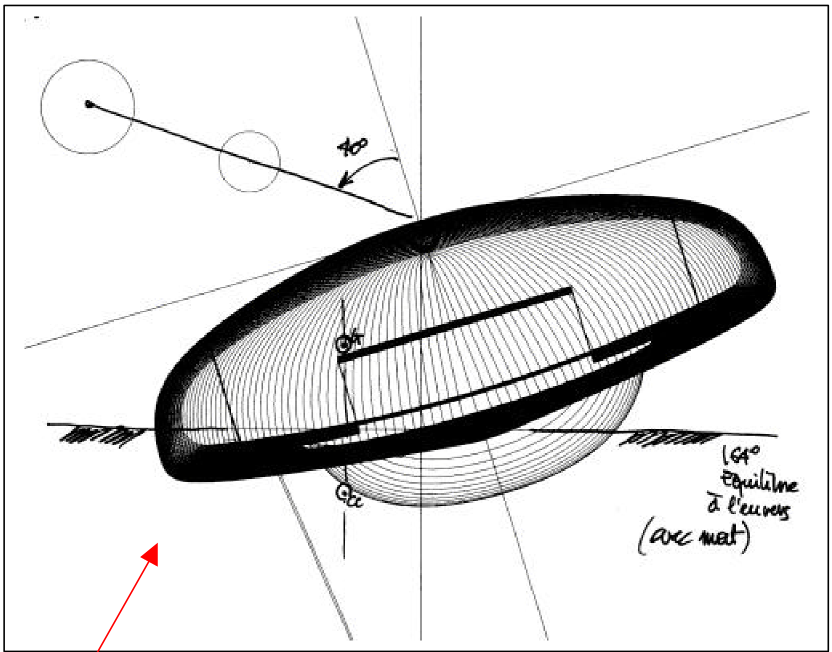
2/Keel Cranked and Ballast full.

When the boat is capsized, keel on the centreline, the angle of stable equilibrium is 180°. If one has the keel cranked to the maximum rotation (this rotation is perhaps greater than that permitted for racing – limited by 10° of heel) for example 40° (bulb of 3.3 tonnes). The angle of stable equilibrium is established at 164° for our model.

Increasing the angle of rotation of the keel modifies very little this equilibrium. In this first simulation the mast is included as a volume not watertight, this assumes that the boat has not been dismasted. The simulation indicates that positions of unstable equilibrium are:

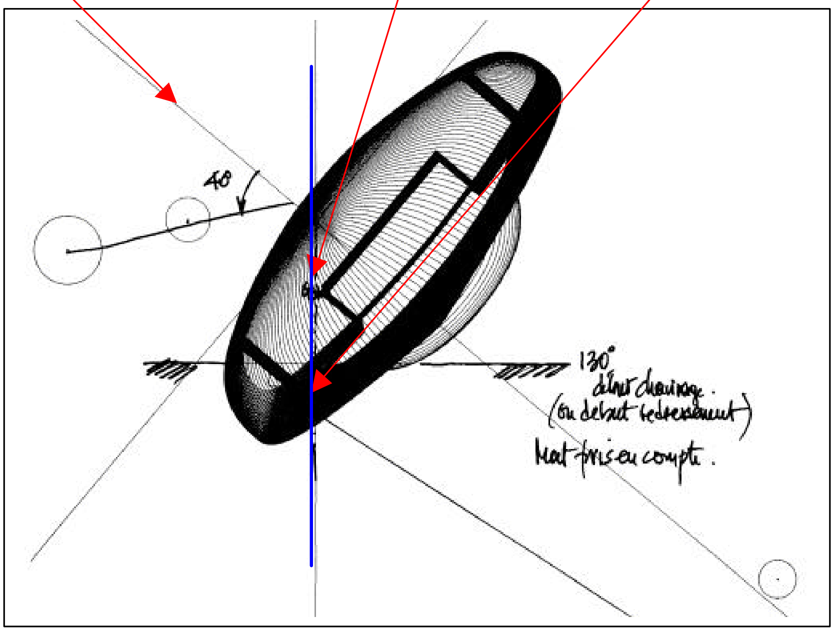
AVS1 = 130° on starboard

AVS2 = 256° (104°) on port



Stable equilibrium (capsize) with mast and moveable keel at 40°

Unstable equilibrium center of gravity center of buoyancy



This signifies that on starboard, it will need to go 164-130 = 34° to find this position and that on port, it will need to go 256-164 = 92°. We would be able to abandon the solution to return to the normal position by tipping the boat on port (92°) and envisage the other side (34°). To perform this operation it will be necessary to flood several ballast tanks on the lee side (the side that the keel is canted to) and to count on the heel to be made by waves (perhaps as much as 15-20°). It is not won.

To count on the returning rotation to happen, look at the design of the boats in the position of unstable equilibrium(AVS). I think that on a calm sea the re-righting of the boat will be difficult, except by introducing a lot of water into the front of the boat, this would re-right it, but it would immediately render it very dangerous due to the phenomenon of “free-surface” effect and on the longitudinal trim. The pumping of the flooded compartments is impossible to do quickly because the boat does not possess sufficient energy available instantly to run the pumps.

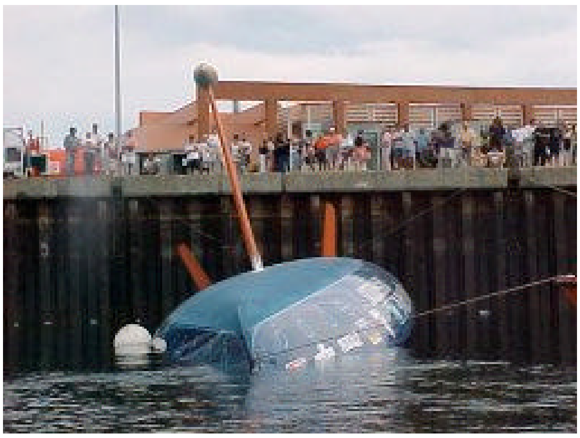
It is not evident that to increase the angle of cranking of the keel will improve the re-righting capacity.

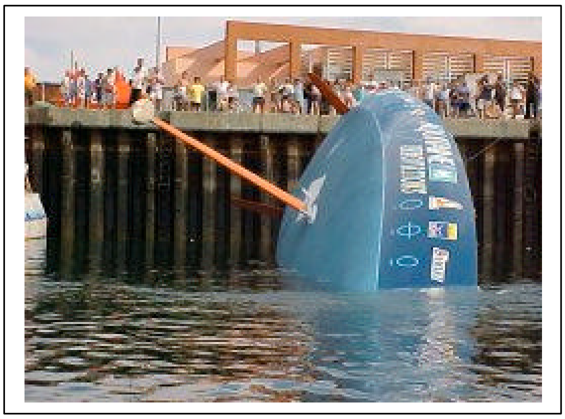
The element which is the most helpful to re-righting is the geometric form of the deck and cabin roof. The ratio 5/1 has obliged the architects to design the cabin roof with more volume (not height than those existing) and the decks with a bulge. This enables the boat to have more bow down trim (the transom does not touch the water) this limits the transverse movement of the centre of buoyancy and the amount that the boat turns (164° for our model at AVS with ballast and keel cranked)

3/Ballast

When the boat is only fitted with ballast tanks the problem is the same except that the angular values are established around 170° and that of unstable equilibrium around 127°, all for our model. The angle taken on the side the most favourable is of the order 140°, this is very important because the ballast tanks are already full and there is no good means to be able to refill to make the boat heel and attain the unstable equilibrium position. In this case only the volume of the cabin roof and the deck will permit the re-righting of the boat, because the angle of unstable equilibrium will be too big, the angle of heel found will be less than this.

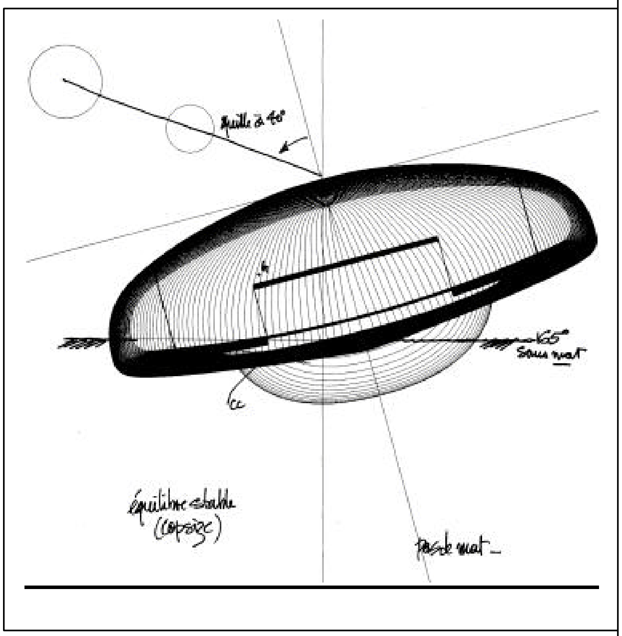
To solve this problem, the skipper introduces water into the bow compartment. The skipper open an hatch on the deck (on this boat 16 T of water). The boat is now upright, but the stem is entirely immersed. That means that stability (upright) is very bad.

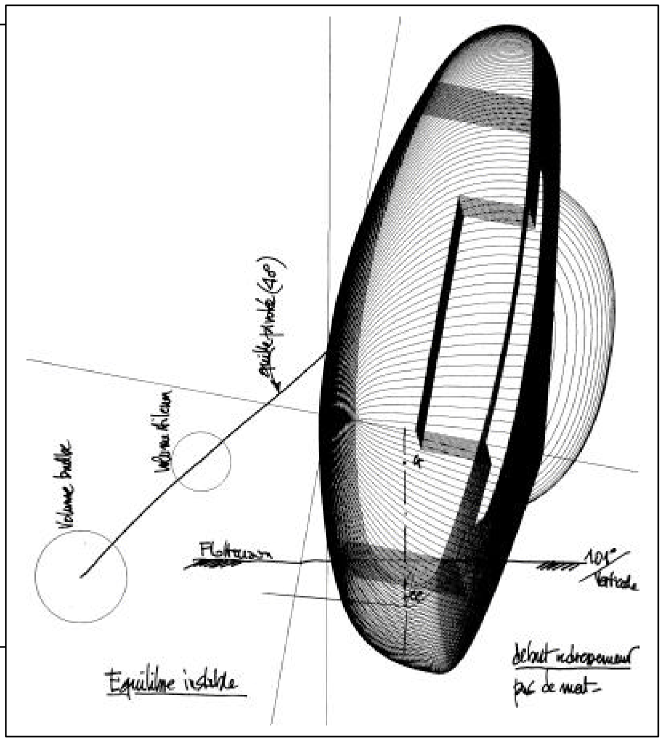




4/Simulation without the Mast

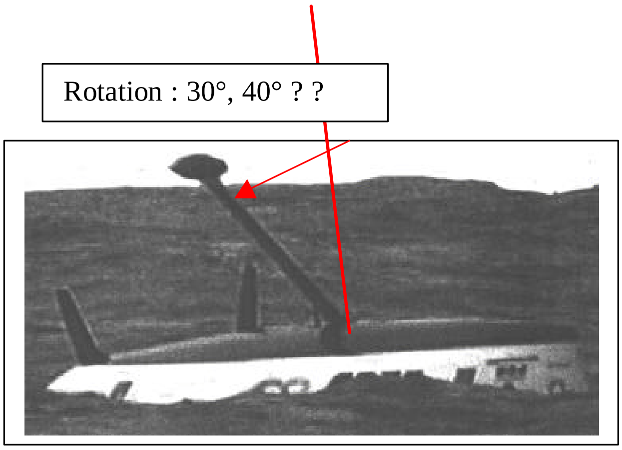
We have made in the same model of boat a simulation of re-righting without the mast starting at the capsize position, with a keel of 3.3 tonnes, cranked at 40° for a displacement of 9.7 tonnes. The results are impressive on our model. The position of capsize is established at 166°. The position of unstable equilibrium is established at 101°!!!!!





This signifies that it will be necessary to make 65° to attain the

position of unstable equilibrium and to see the boat re-right.
In this simulation, the hypothesis are extremely unfavourable, in effect when the mast is not taken into account in the calculation, we have voluntarily reduced the displacement of the boat. This translates into a trim by the stern, which is unfavourable for re-righting.
One remarks that this situation although hypothetically rare has happened.



*“**PRB**” Isabelle Autissier in south pacific ocean*

Experience “Whirlpool”
Recently Whirlpool made a first by making a re-righting of the boat starting from 180° capsize. This could be considered contradictory to the analysis in paragraph C, I do not think so, the analysis above took into account the generation of 50’ and 60’ existing and which sail or have sailed with more or less luck (don’ t forget that Amnesty capsized three times, Group LG once, PRB once and remained capsized). Fleury-Michon had more luck in remaining stuck at 90°. Whirlpool is a boat which I qualify[1] as “not normal” in the generation 60’, not normal because it is the first boat to posses a deck with a very generous bulge and a cabin roof not higher than the others, but more voluminous and which develops on a longer length of the boat. This particular geometry of the deck and cabin roof enables a ratio of the areas of the stability curve of the order of 6/1 or 7/1. This ratio is equally important as an empty curve of stability (keel cranked to 20°, boat empty) is tangent above the axes of the abscissa. The boat in this configuration (empty) has the stability of a liferaft. This signifies also that loaded (that is with 2000kg of added weight and a centre of gravity much lower, changing from 0.9m to 0.3m) the problem will be different, the boats will re-right, but it will need a cranking of the keel to 35 to 45°.

It should be understood the difference between a boat that remains inverted (PRB with the keel at 35 – 40° and a boat which rights itself (Whirlpool), these are an important difference.

The results of this experience (test to 180°) interesting that they are, do not replace the measurement and calculations of stability of the boat in the loaded conditions close to which it will be at the start of the race. The test to 180° (boat empty without mast) which is complex to perform, does not improve our knowledge of the general stability of the boat, because all the other measurements shall be made with the mast and practical load, it is for this reason that the requirement is not justified.

[1] This study was written in December 1999, now all the 60 ' and 50 ' adopted " philosophy " WHIRLPOOL, but the old boats always sails. AQUITAINE takes part in Around Alone this year.

This test at 180° does away with validating the choice of ratio of 5/1 and the minimum AVS of 125°, but does not permit on its own to define the stability of the boat.

If the form of the hulls resemble each other, the other parameters are very different. The first generation of Open 60's preferred the light displacement with ballast of 2 – 2.5 tonnes, very wide on the deck, the ratio of Bmax/BWL is large and above all without a bulging deck nor a cabin roof of large dimensions.

It is these latter parameters (superstructure form and increase of ballast) which are decisive to assume re-righting. To be convinced, try to capsize an empty sugar box in your bath, you will find it is impossible, it is like image of PRB or that of the tragic Group LG upside down. For sure they have ratio of ballast/displacement much larger (they are now at 3.3 tonnes of ballast) but above all it is associate with voluminous superstructure.

The photos of Whirlpool upside down show that the transom does not touch the water, this signifies that the trim of the boat is by the bow, caused by the form of the roof and deck. Our model in the capsized position is itself resting on the transom, is one of the reasons for its stability upside down.

Why the Problems?
Big debate, often dominated by the syndrome of weight, of lower centre of gravity, of minimising pitching etc, by the desire to apply to round the world that which pays round the buoys. Don' t forget that sailing is a mechanical sport, that the gain of speed is unique but at the time of initial conception of the boat the safety, that is organised afterwards, this does not exclude certain double language.

The VPP (programs predicting speed) don' t do more than integrate the mathematical equations which for a hull model and wind statistics are how you gain a day on the winner of the preceding edition of the Vendée-Globe or another course, but the VPP does not take into account the stability. There are many stability programs, but those which take into account the volumes of cockpit, cabin roof, the insertion of ballast, the cranking of keels, the volume of bulbs are also rare as they are expensive.
When a single dimension (LOA) represents the rule, all is suddenly authorised, more often than not the only constraint that would be accepted by the competitors without any controversy or discussions would be the limitation of draft at 4.50m for the simple reason that they already are not able to access marinas and some still dream of 4.8-5.0m.

Too much liberty favours architectural excess, only the rules framing the architecture permit the development of these boats, with the maximum of safety for the crew. All the classes called “open” have respected one day under a restricted rule.

D-Conclusions

The FICO regulations permit the correct evaluation of the stability of a boat that is in a configuration without ballast and keel on the centreline or under the effects of ballast and keel cranked. It is indispensable to treat the stability of the boat with very capable software which takes note and accounts for the volume of ballast, of the cockpit, of appendages etc.
This supposes that the architects supply the data files of the hulls and appendages and that the boat is built in accordance with the computer model. The race committee is obliged to keep confidential the document submitted by the architect, builder, sponsor and skipper.

Finally I leave the conclusion to Marc Lombard (Naval architect):
“More than bare re-righting [in a harbour], the boat's dynamic stability boat is a strict measure of the stability made by an officially recognised measurer and an in depth examination of the plans of the boat by an independent observer”.

17 January 2000, Jean Sans