Corbin 39 Study – Theoretical Analysis - Initial Results re Hull Form and Static Stability

by Jean-Francois Masset, David Sharman, and Alain Lebeau

rev 3 dated 5 May 2020

1 Working document

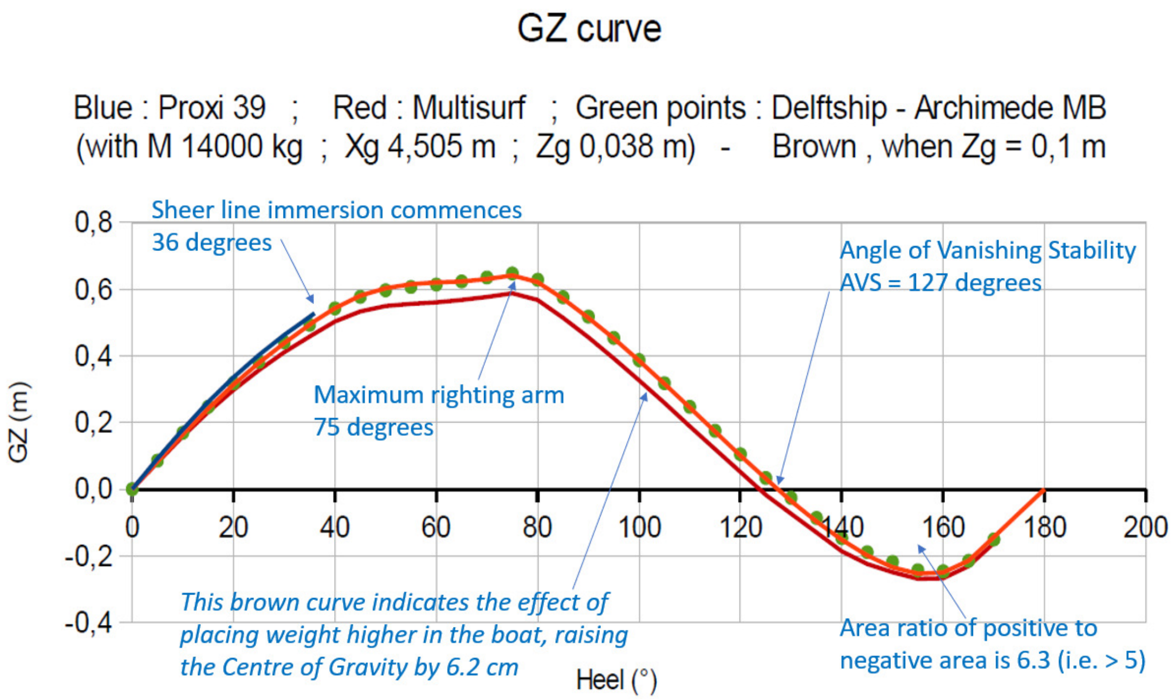
This is a working document setting out the interim results of an ongoing study into various aspects of the Corbin 39. Conceptually this document is one of a series:

1. A study of the anecdotal evidence in respect of weather helm.
2. A theoretical analysis of weather helm and various options for owners.
3. This reproduction of the lines plans, the hull form, and analyses of displacement, trim, and static stability.

Future areas of interest are hoped to include sailing performance (i.e. a VPP) and dynamic seaworthiness (e.g. STIX). Because this is a working document it may contain errors, and will likely change.

2 Summary and recommendations

Summary : We have made reasonable assumptions that can be summarized as: an operating displacement of 14,000 kg (30,865 lbs); neutral trim initially; and a Centre of Gravity ("Zg") placed 3.8cm above the Design Waterline (this is just below where the saloon table top is). We have cross-checked output data from 3 numerical tools (programs) and obtained good agreement for a GZ curve as shown with an AVS of 127° and an area ratio of 6.3. The effect of trim, displacement & draught differences, and Centre of Gravity were also investigated, e.g. when assuming Zg = 0,1m (assuming the worst), the stability is still good , with an AVS at ~ 123,7° and an areas ratio of 4.94.



Recommendations : The study makes important assumptions regarding hull dimensions, displacements, and weight distribution. Therefore it is recommended that these assumptions are refined through a process of accurate measurement and an inclining test of a reference hull, plus reporting by owners of actual displacements by way of draft and "hook weight" information.

3 Authors

Jean-Francois Masset : Much of this study is carried out by Jean-Francois Masset who is a retired naval architect who has most generously given his time and knowledge to assist the Corbin 39 community. He worked for many years at Ifremer, the French oceanographic research institution.

Alain Lebeau : Like Jean-Francois is a retired ex-Ifremer, in his case an ex-biologist converted to the hydrodynamic science by passion.

David Sharman : An energy-sector engineer and Corbin 39 owner, very happy to learn from experts.

We owe Jean-Francois Masset and Alain Lebeau many thanks for their most kind support to our Corbin 39 community.

4 Study tools

Gene-Hull: A free design programme written by Jean-Francois Masset called "Gene-Hull" in a spreadsheet format that is ordinarily used for early stage yacht design when there are a lot of design options under consideration, before down-selecting into detailed studies of a preferred design. However in this study Gene-Hull is being repurposed to analyse the many different sail & spar layouts that the Corbin 39 was built with, and then to theoretically assess the performance and the development options open to each layout. Gene-Hull can be downloaded from https://www.boatdesign.net/forums/design-software/ (use Gene-Hull in the <<Search>> function).

DelftShip : In the free version DelftShip is a hull form modeller which allows creation of a 3D model of a ship, and calculation of very basic hydrostatic data. We are only operating the free version at this stage. The professional version carries out the full suite of stability analysis. See https://www.delftship.net/

Multisurf : A professional 3D design tool for complete marine design as used by Alain. See http://aerohydro.com/.

ArchimedesMB : A low cost (or free, for the key functions), benchmarked, software utility for generating hydrostatics and cross curves (static stability curves) for arbitrary floating bodies. See http://www.naval-architecture.co.uk/ Support appears to have stopped in 2006, and it is buggy, but it is interoperable with DelftShip-Free and so allows the stability analysis to be carried out free. Needs a small calculation spreadsheet to extend the KN output to become a GZ curve. For that you can write your own simple spreadsheet or use "**GZ y RM cada 5 grados**" off the internet.

Many other spreadsheets and various image editing software have been used. **Gimp** is especially useful for rotating images in increments of less than 1-degree to get them aligned.

5 Methodology

As well as giving results it is worthwhile explaining the methodology so that others can reproduce the results if they wish.

1. Gather available (paper) design & construction data.
2. Build three digital models of the hullform and compare the geometrical and hydrostatics results with each other, with the real boats, and with the available design data. Eliminate errors.
3. Produce digital lines plans, offsets tables, etc from the models.
4. Identify the displacement(s) of interest, and create a mass distribution model.
5. Analyse static longitudinal trim and draught. Build an abacus (a basic spreadsheet tool) connecting the observed fore and aft draughts (at rest on a flat sea) with the displacement, the XcG, and the Trim.
6. Analyse the transverse static stability, especially the GZ curve.
7. Document the results, and make any recommendations.

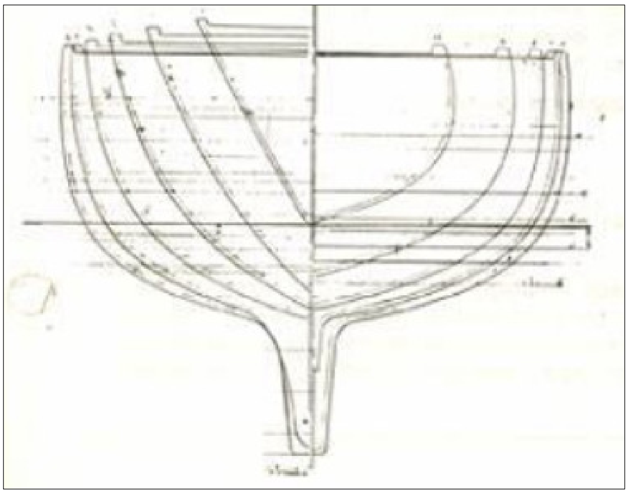
5.1 Gather available data

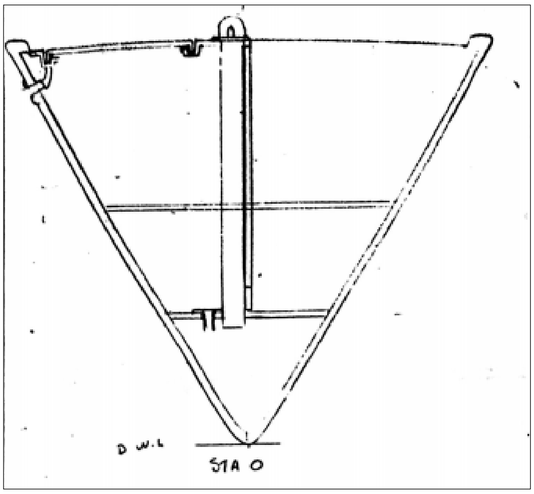
5.1.1 Drawings

For studies of this nature the most important key data required is a set of paper lines plans. If they are not available a photogrammetry study of an actual hull is required.

The Corbin 39 was designed by Robert Dufour and hulls were moulded by the Marius Corbin yard. The original lines plans were not knowingly fully published by the Corbin yard, however sufficient public domain information was published either deliberately or inadvertently by the Corbin yard to substitute for this.

In particular the transverse sections can be seen in two places. Firstly they are shown in a marketing image used on the cover of the first brochure, dating from June 1979 when they had moulded the

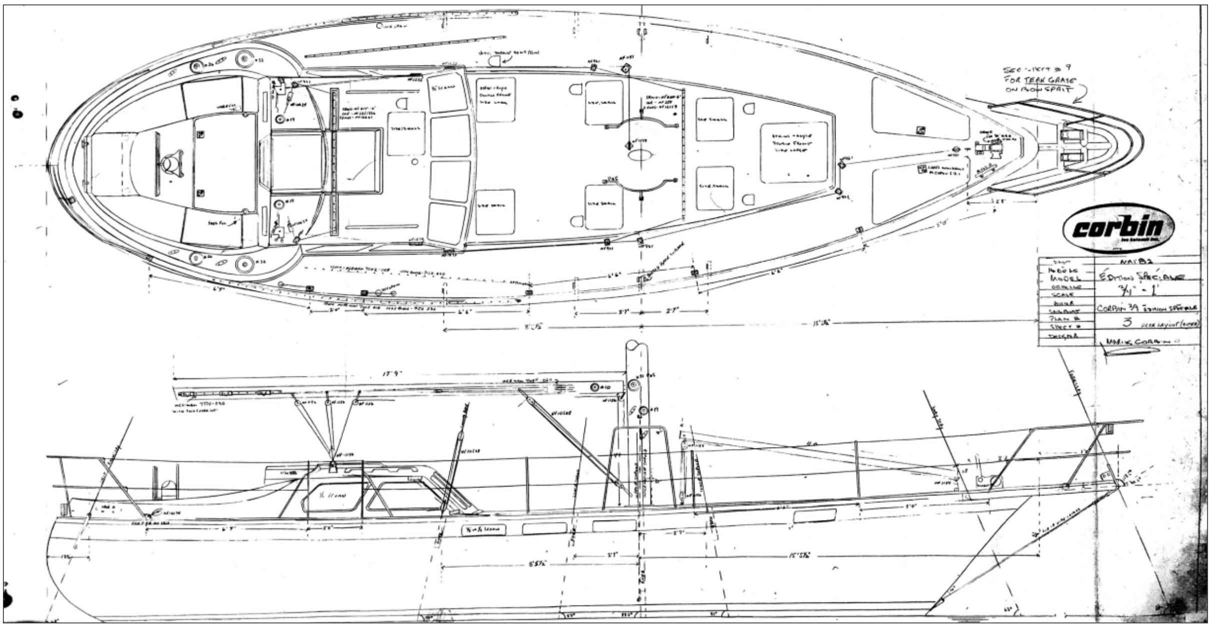




first ten or so hulls, but apparently did not yet have completed boats to take photographs of. Secondly in the construction (fitting-out) drawings, particularly sheets 4 and 5, many of the ten framing stations are shown. Also the plans give the side elevation and plan view. We can scale all of these by reference to known dimensions on the boat, or occasionally by dimensions in the drawings themselves. These are of course not full lines drawings, as they do not give the waterlines, or the buttocks, but with care and by reference to the actual boats they suffice and are public domain.

There is another source of the lines drawings which, whilst available to the public, comes with the restriction that it may not be reproduced. The well known yacht designer Dieter Empacher was commissioned to fit out hull #8 “Stingray” and he obtained a set of original lines drawings directly from Robert Dufour, issued as a professional courtesy. However Dufour was also mindful of his professional obligations to Marius Corbin and placed a usage restriction on them. In turn when Empacher transferred all his drawings & documentation archives to Mystic Seaport maritime museum archives this restriction was interpreted as being no professional usage, and is placed upon any copy. However we are able to use them as a way of checking any modern digital plans we make.

We have a copy of these original Dufour lines plans, and we too are subject to the same transferred restriction. Because of the restriction on them we do not reproduce it here. However the information we are setting out in these studies is consistent in respect of the hull itself, except where a note otherwise is made. Also the mk1 hulls and the mk2 hulls are identical, likely from one single mould. It was only aspects of the deck, cockpit & superstructures, and the rig that have the well-known differences between mk1 and mk2 and they are either not relevant or not material in the context of the stability issue.



5.1.2 Data discrepancies observed

Sheer line position

There is a minor discrepancy of 1” between the lower freeboard quoted in the Corbin brochures and the higher freeboard stated on the Dufour lines plans. The same discrepancy exists both fore and aft. It is likely this reflects the teak caprail at the hull edge. We modelled using the lower number, i.e. just the fibreglass mouldings. The key numbers in the Corbin and Dufour drawings used are:

LOA: Dufour = 465-3/4” (1183.00cm); Corbin = 465” (1181.10cm)

BOA: = 144” (365.76cm)

LWL at DWL: Dufour = 382-1/2” (971.55cm); Corbin = 383” (972.82cm)

Draft at DWL: = Dufour & Corbin = 5’6” = 66” (167.64cm)

Freeboard fwd at DWL : Dufour 62” (157.48cm); Corbin = 61” (154.94cm)

Freeboard aft at DWL: Dufour = 53” (134.62cm); Corbin = 52” (132.08cm)

Maximum hull draught below DWL datum (exc keel) at station #5: Dufour = 30” (76.20 cm)

Mast position in the actual mk2 vs the drawing

In many side elevations of the mk2 it shows the mast at a location intermediate between the two intended locations of the mk1. Measurements from actual mk1 and mk2 Corbins show this to be incorrect. Provided that the mast is not used as a datum point for measuring off these drawings this does not affect hull hydrostatic calculations. It is noted here so that people are informed.

Waterline position, and displacement

There is an issue regarding brochure statements of displacement and the position in all drawings of the design waterline (DWL). See step 4 in the analysis for a discussion of this.

5.2 Build digital models & compare

Two digital models of a Corbin 39 were built, one in DelftShip and one in Multisurf. A third digital model was created in Gene-Hull of a hull that approximates the Corbin 39 except for the very aft of the stern cut at mid overhang, and this is termed a “Proxi39”. The ends of the hull do not affect static stability and so there is no reason to force the parametric modelling engine within Gene-Hull to faithfully model these ends.

Inspection of the keel suggests that it is a NACA 4digits foil (Note : t/c(%) actually evolves from 12.45 to 8.75 from root to tip chord). These were developed in the 1930s and are in widespread use in industry. As the maximum thickness (as drawn on the linesplan) is slightly behind the 30% apparent chord, it is supposed that the profiles to be truncated to ~ 97.5% of the chord, which is a usual method to avoid too thin rear edge to build and maintain, and vortex release causing vibration. The original lines plan confirms foil truncation in this manner.

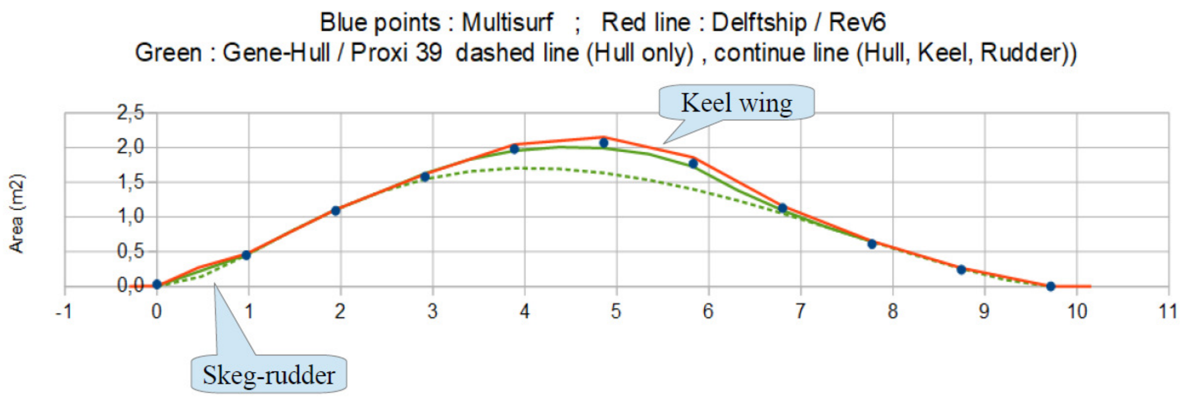
The three digital models were compared and found to be in very close agreement, certainly close enough for the analysis in question. In general, values differences within 1-2 cm and/or 2-3 % are quite common in such difficult re-engineering exercise, but this does not prevent us from carrying out a good enough analysis. The comparison of the three models is the safety net to detect values which are outside that kind of imprecision, reflecting a bug somewhere.

Below is an extracted table of some key dimensional data and the graph of the sectional areas. See Appendix 1 for the full 4-page file of these results.

Corbin 39 - Cross-check of the hydrostatics data – as for 23 04 2020

With reference to the same linesplan and its data

	Gene-Hull (Proxi 39 output)	**Multisurf** (Data in annex)	**Delfship** (Rev6 / DS 18-04-20)
Lwl (m)	9,716	9,707	9,743
Loa (m)	Not relevant (aft overhang cut)	11,695	11,826
Bwl (m)	3,421		3,408
Boa (m)	3,710	3,63	3,658
Hull body alone : volume (m3) at X,Z position	9,52691 at X 4,516 m Z – 0,259 m	9,45600 at X 4,505 m Z – 0,262 m	
Total volume (under H0) : (m3)	10,580	10,630	11,084
>> Displacement (kg) (with 1025 kg/m3)	10844	10896	11361
LCB total (m)	4,518	4,547	4,543
, in % Lwl	46,50	46,84	46,63
ZCB total (m)	-0,344	-0,350	-0,361

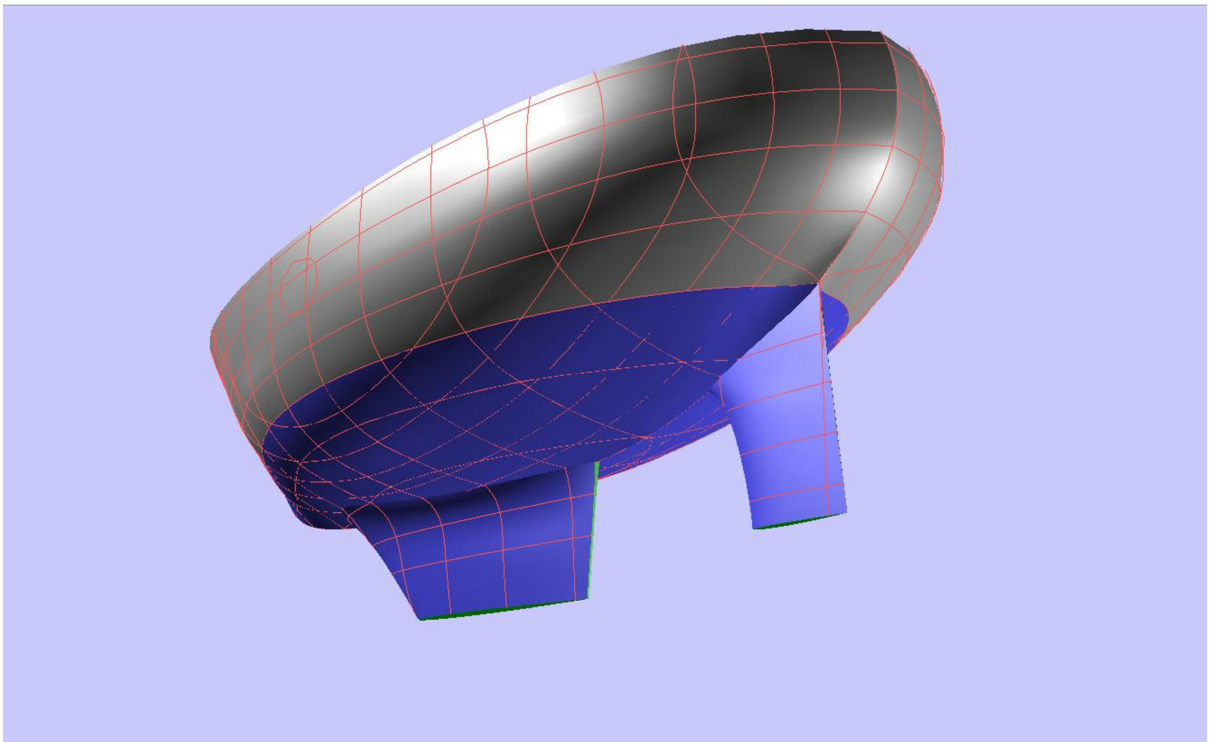


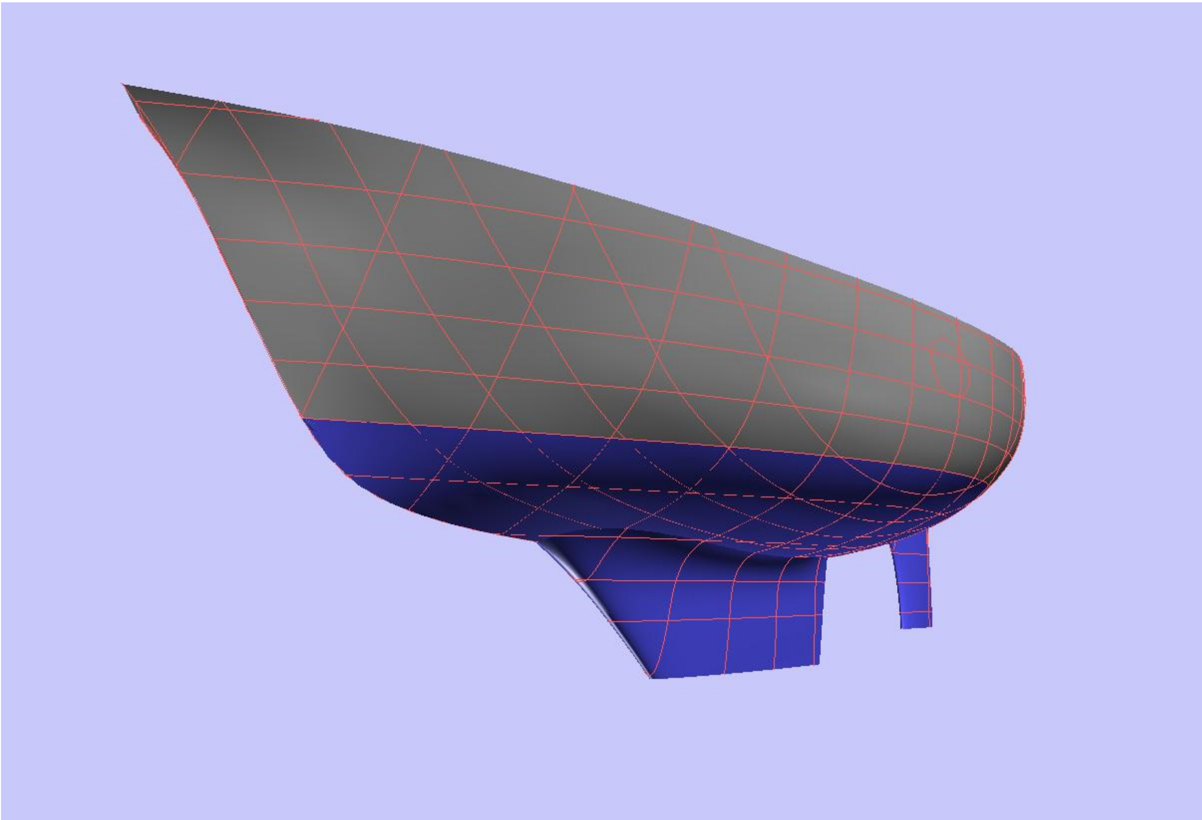
Because this is an ongoing study and the various models are evolving there are occasional discrepancies in some of the numbers in this report, typically between different model versions.

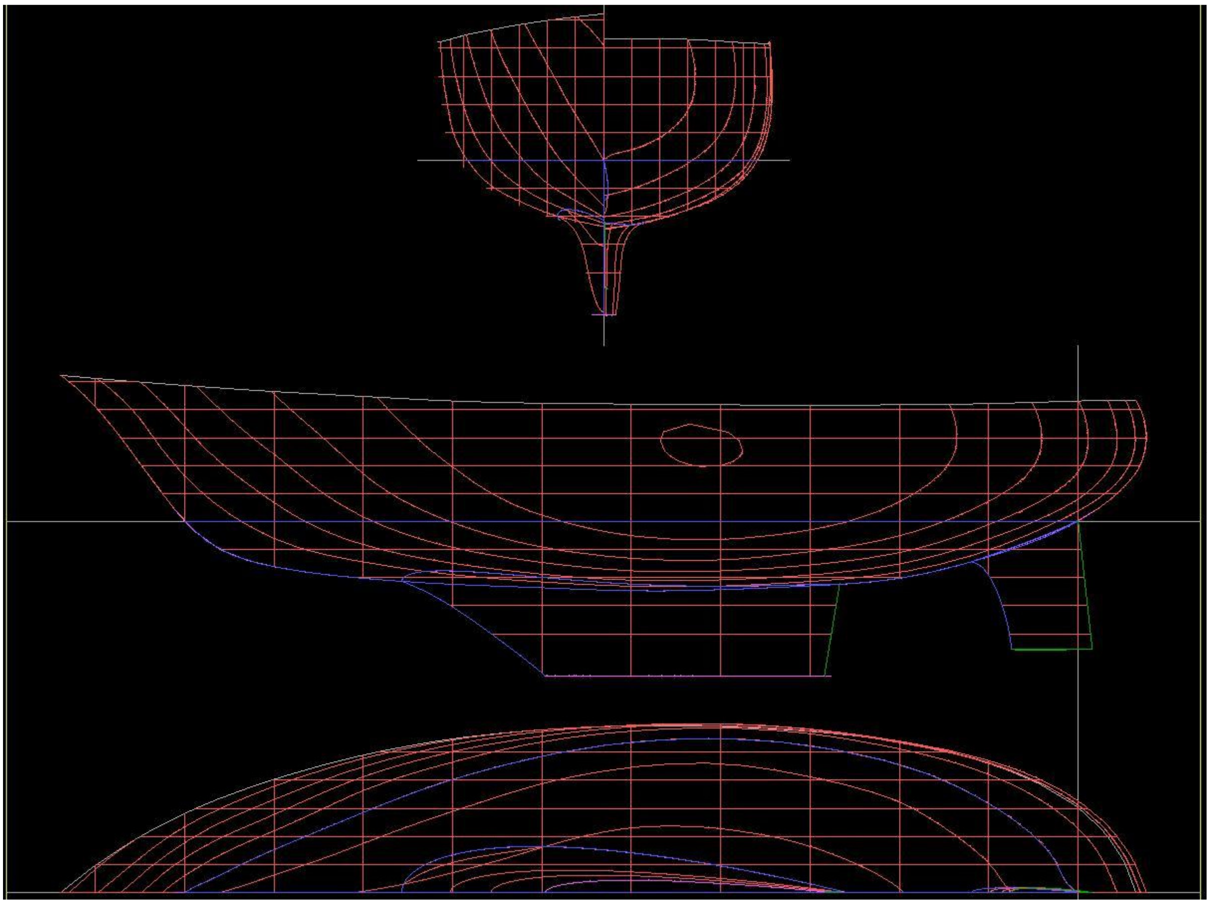
5.3 Produce digital lines plans etc

These are just samples of the visual outputs from the various programs as “eye-candy”. See Appendices for more info. An important point is that we now have these on file for future use.

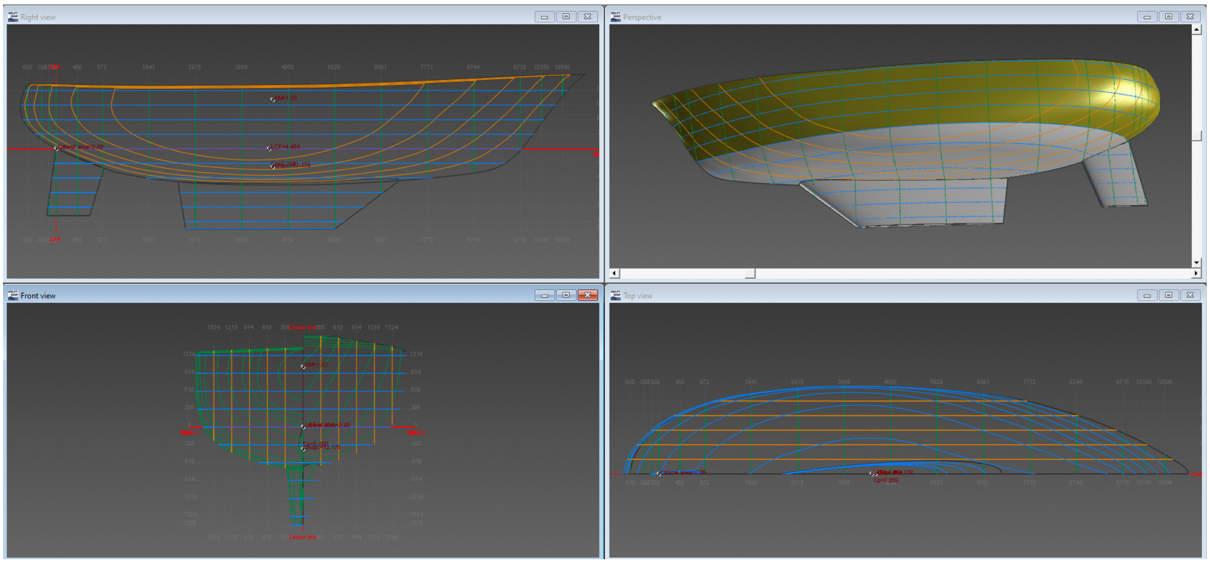
5.4 Multisurf for Corbin 39

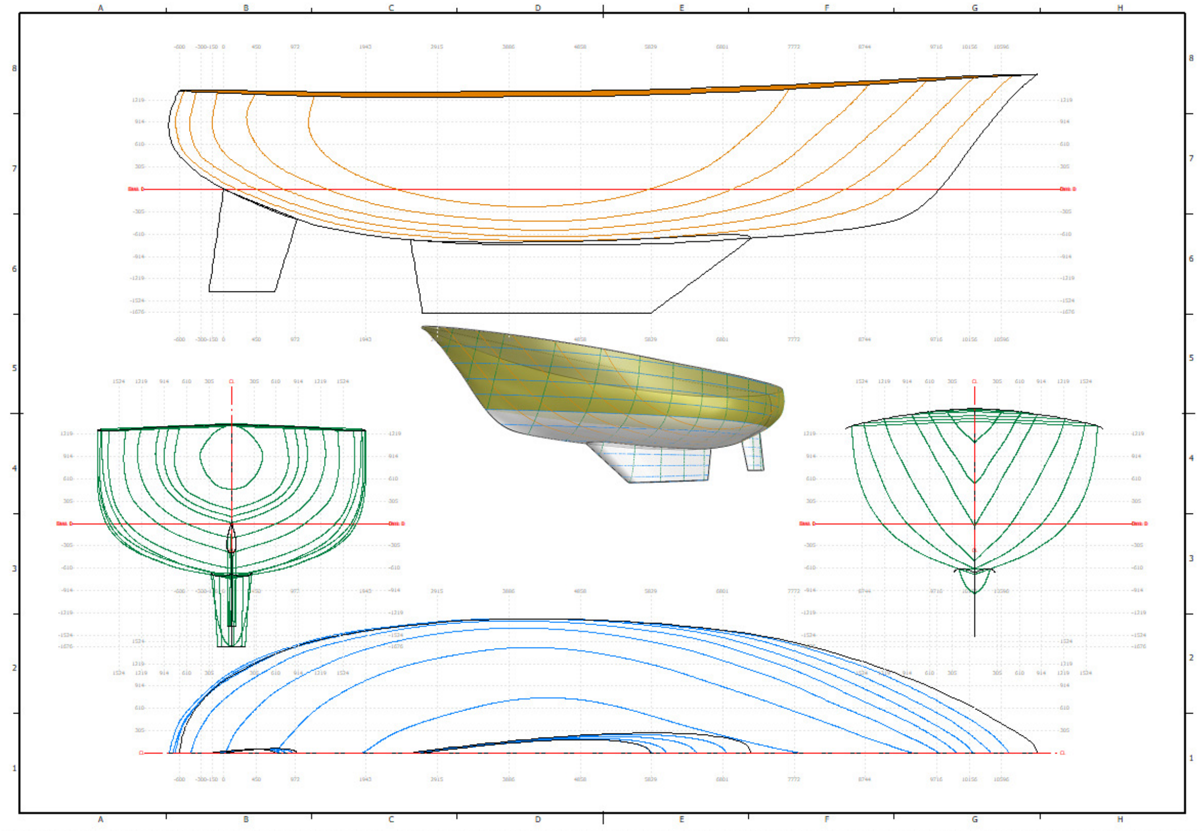




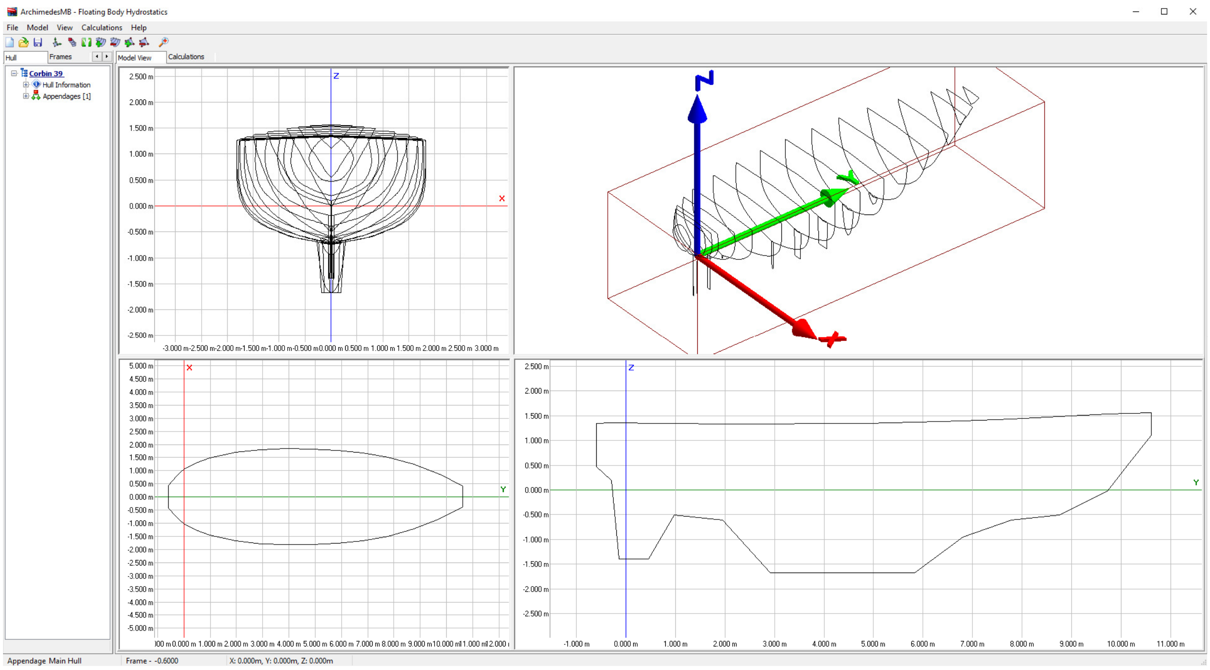


5.5 DelftShip for Corbin 39





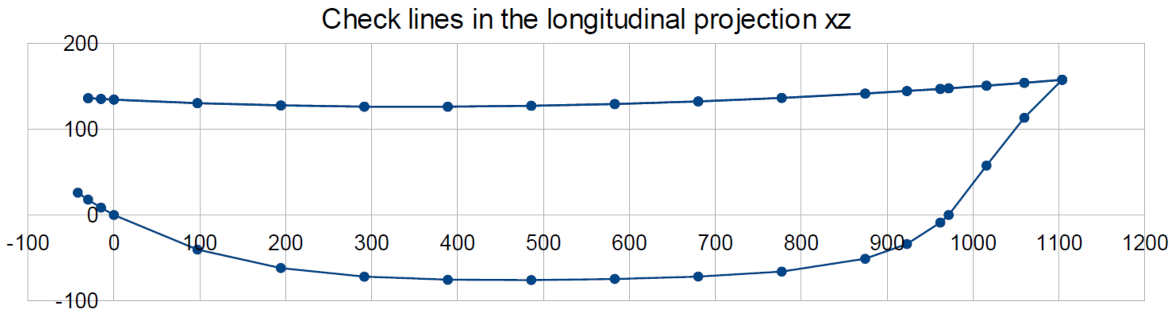
Which feeds into ArchimedesMB :

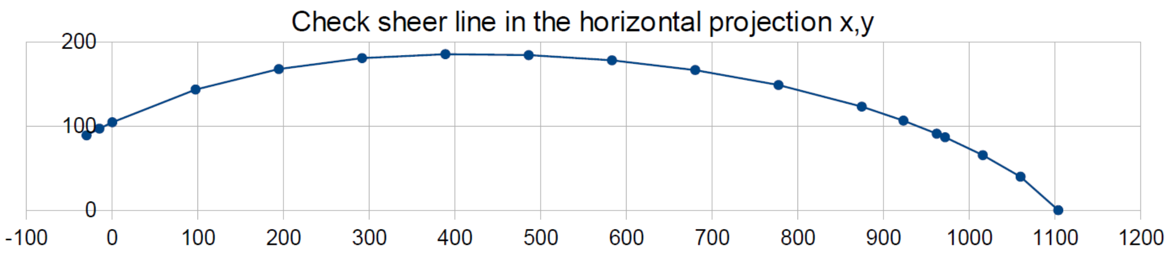


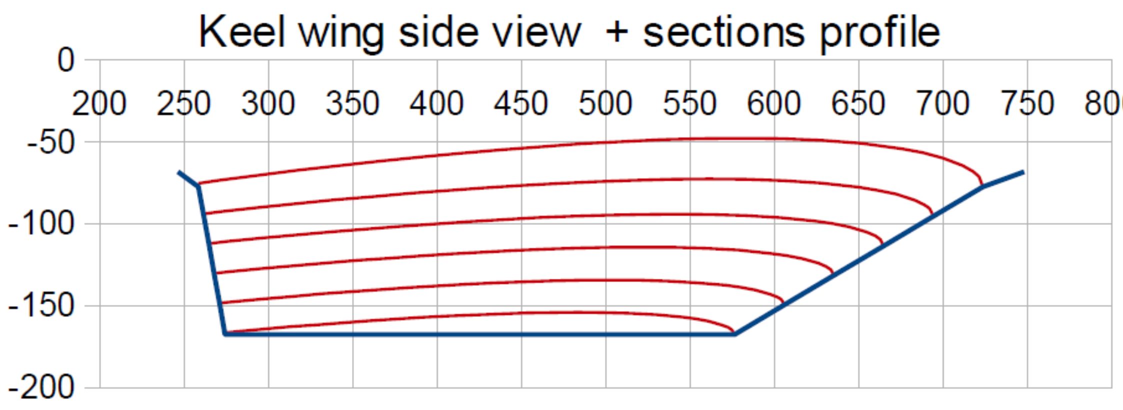
NOTE:

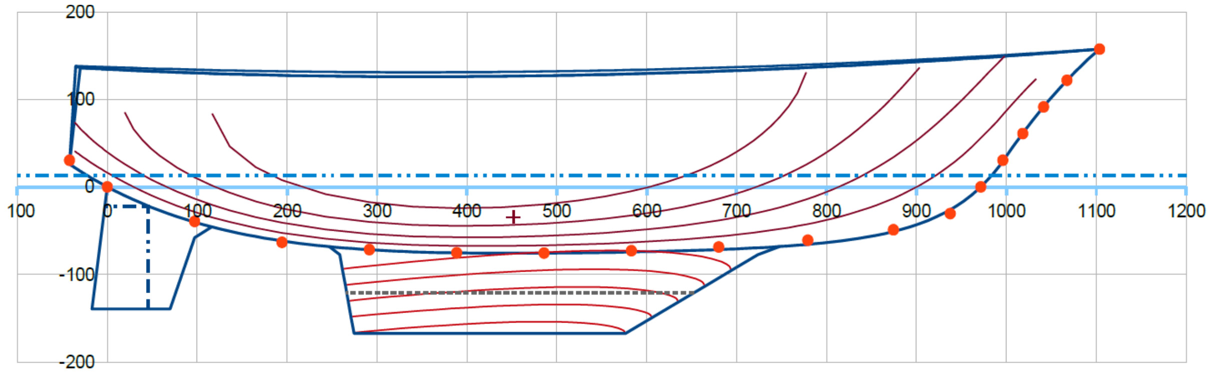
1. ArchimedesMB uses a different notation for x,y,z than is normal. It has x for lateral dimensions whereas DelftShip uses x for centre-line dimension.
2. ArchimedesMB appears rather unstable. In this exercise it would not run below 13mt, or above 171-deg.

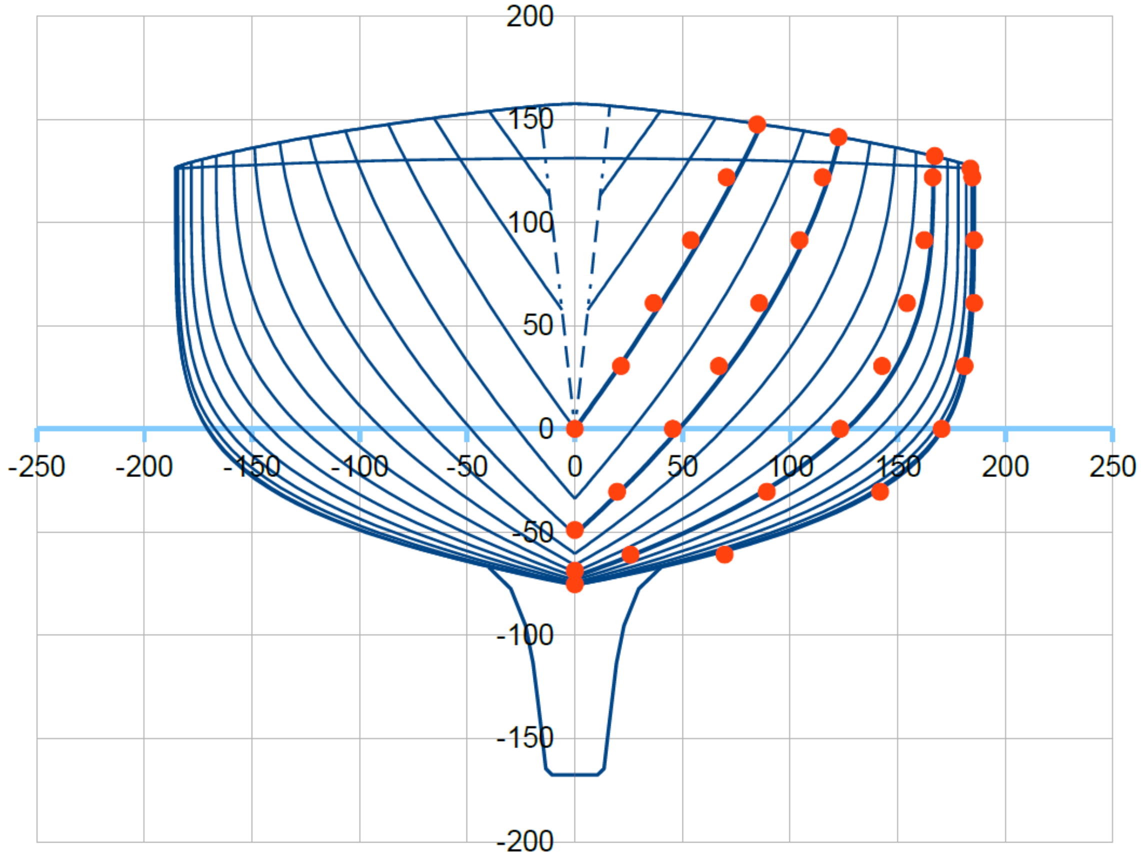
5.6 Gene-Hull for Proxi-39







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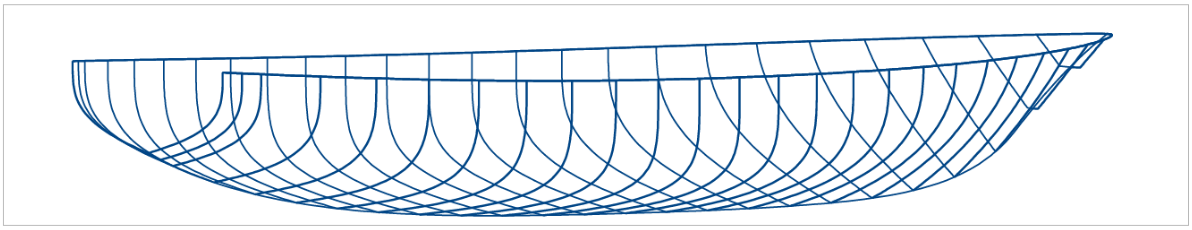

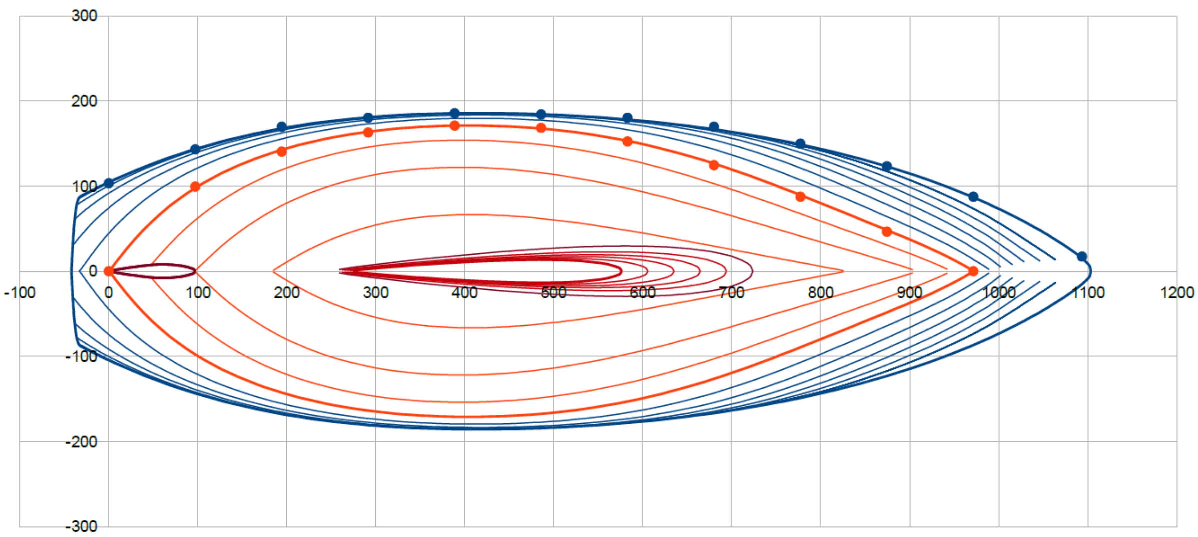
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5.7 Identify displacements of interest, create mass distribution model

5.7.1 Displacement and draught

If you look on the many drawings of the Corbin 39, irrespective of whether they are Robert Dufour designer drawings, or Marius Corbin yard construction and fitting out drawings, you will see the Design Water Line (DWL) marked. It passes horizontally through the intersection of the aft edge of the rudder & skeg with the stern centreline chine of the hull. If the boat is ballasted to the design waterline then the keel will draw 5'6" (167.6 cm), which is also a well-marked feature on the various drawings. The base of the keel is itself horizontal at zero trim.

When the hull is immersed to the design waterline it will displace approximately 11.084 m3 of water, or at least that is the figure from the DelftShip model rev6. With a density of seawater[1] of 1,025 kg/m3 this corresponds to 11,361 kg. That can also be stated as 11.361 metric tonnes (mt, note the extra 'tes' in 'tonnes') or is 25,046 lbs in imperial pounds (US & UK).

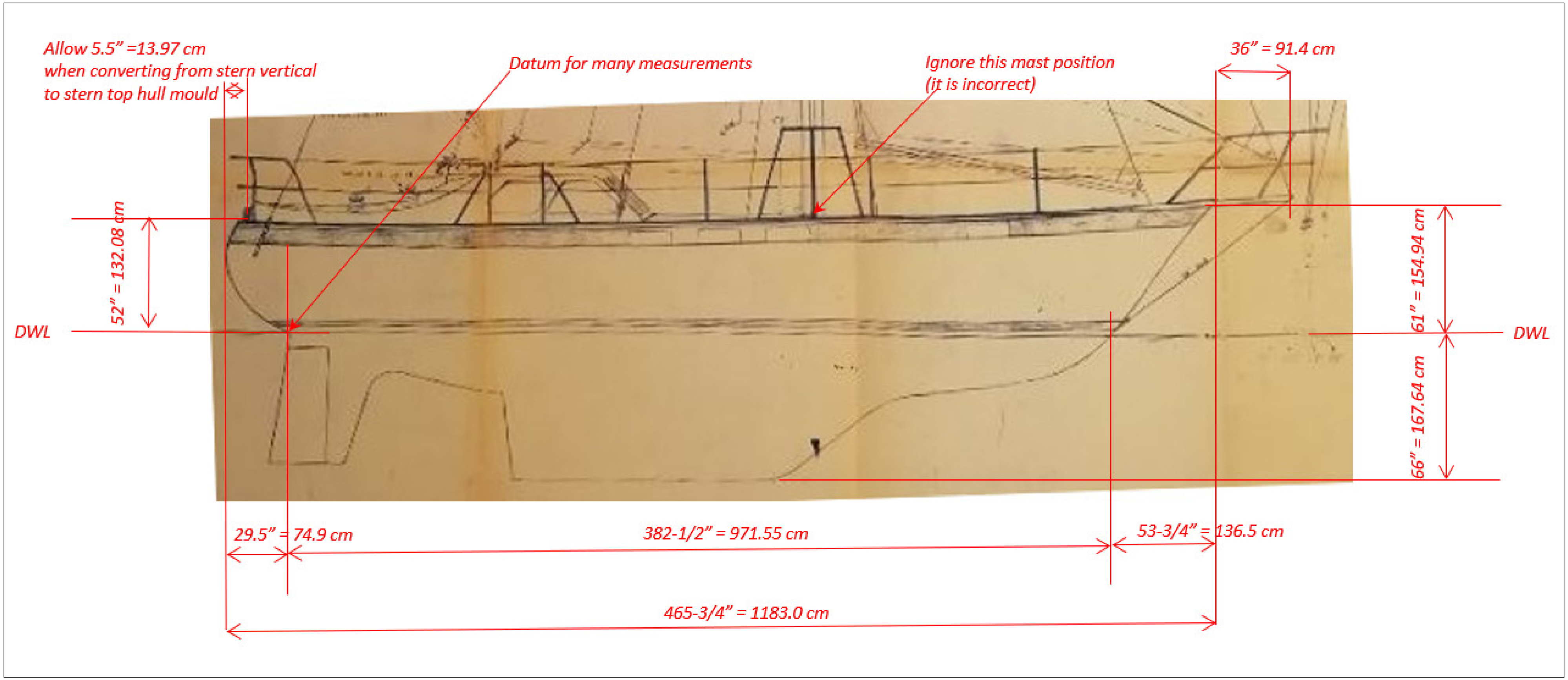
These digital model figures are undoubtedly wrong in some way, that is normal. We have carefully compared all three models and they are within a reasonable range, though not quite as close as we would like : DelftShip gives 11,361 kg (25,046 lbs); GeneHull gives 10,844 kg (23,907 lbs); Multisurf gives 10,896 kg (24,021 lbs). So if the actual Corbin 39 hull has been built in accordance with the various drawings, then those figures will correspond to reality. What this means is that if a Corbin is floating freely in seawater, immersed precisely to its design water line, and with no fore or aft trim, then if it is lifted carefully by a crane that has a calibrated load cell, then the "hook weight" of the crane will show 11.361 metric tonnes or thereabouts.

Of course the actual Corbin 39 will not have been moulded exactly as per the drawings, and our digital models will also be incorrect in some ways. The only way for us to know what is reality is for us to carry out that experiment of weighing a Corbin that is floating ballasted to its design water line. We could then tune our digital models to match reality. This is an important test we must conduct one day, along with other accurate measurements.

What we can also read from the various Corbin marketing brochures is the brochure displacement. Ordinarily we would expect this to be phrased as "displacement of X, including Y of ballast". There are two such statements in the various Corbin brochures. In the first (1979) and second (1982) brochure it is stated as being displacement of 22,000 lbs and 9,200 lbs of ballast. In the third (1983) brochure it is 22,800 lbs and 9,000 lbs. This suggests some evolution in their thinking, so some connection to a reality. However there are two obvious problems. The first is they do not state unambiguously whether the quoted displacement (22,000 – 22,800 lbs; or 9,979 – 10,342 kg) is inclusive or exclusive of the ballast (9,200 – 9,000 lbs). It ought to be inclusive, but we cannot be sure although there is one brochure where the ballast ratio is stated as 42% which is fairly conclusive. Secondly even the interpretation of it being inclusive of ballast would be slightly different than the numbers we have calculated.

There are some further issues. The most obvious is that we do not know what operating condition the boat is in when it is at its design waterline and/or its brochure displacement (which we can now see might not be quite the same thing). Is it for example in its "lightship" condition with all tanks empty, destored, and soft furnishings and consumables removed. Or is it in some other more normal but heavier 'working' condition. It is quite normal for brochures to use lightship conditions.

[1] As a matter of historical curiosity, when conducting tests like this for the purposes of the various pre-WW2 international naval treaties that were intended to limit arms-races, it was also necessary to measure the actual density of the seawater and the strength of the earth's gravitational field at the various harbours.



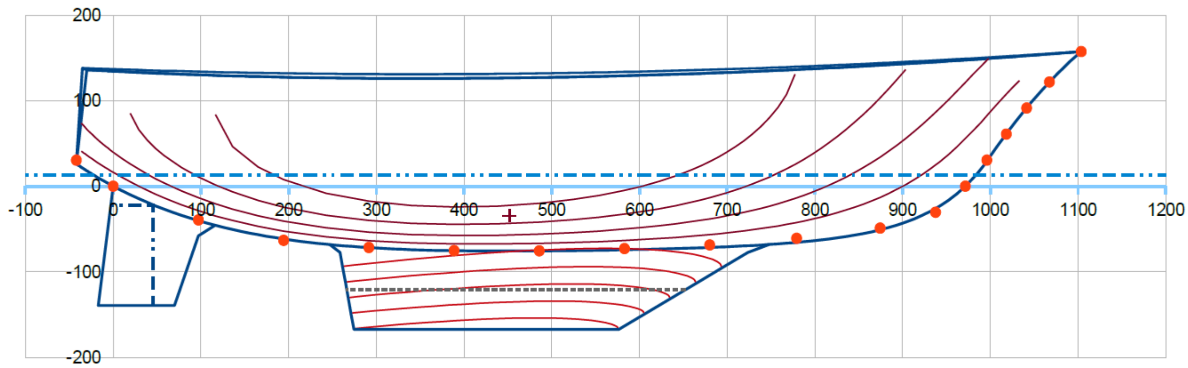
Allow 5.5" =13.97 cm
when converting from stern vertical
to stern top hull mould
Datum for many measurements
Ignore this mast position
(it is incorrect)
36" = 91.4 cm
52" = 132.08 cm
DWL
DWL
61" = 154.94 cm
66" = 167.64 cm
29.5" = 74.9 cm
382-1/2" = 971.55 cm
53-3/4" = 136.5 cm
465-3/4" = 1183.0 cm

Another issue is that no two Corbins are identical. We believe that the recommended ballast for the mk1 shortmast was 6,000 lbs as opposed to the 9,200 lbs recommended for the mk1 tallmast. But also they were all fitted out very differently by many people for different purposes, and then many have evolved substantially since.

Therefore we enquired of Corbin owners as to what their boats weighed, what draught they were drawing at that weight, what condition they were in, and what keel ballast was installed. We received reports ranging from a low of 10.9 tonnes and a high of 15 tonnes but a definite bias towards the upper end of the range, and with this as a typical start or end of season condition. Of course these are from a great variety of crane and hoist weight indicators, but they are a guide.

Our conclusion was that we should use 14,000 kg (14.0 tonnes, 30,865 lbs) as being an appropriate 'baseline' light-ish displacement for carrying out initial stability calculations. This would be more likely to be typical of operating displacements than the brochure displacements of approx 10 tonnes. Similarly we concluded to use a higher waterline (and deeper draught) than the design waterline, so as to correspond with this increased displacement.

For 14 000 kg and assuming no trim, the extra draft is 12.87 cm, shown as the dot-dash blue line in the Gene-Hull drawing below. This brings the draught of a 14 tonnes displacement Corbin to be approximately 180.5 cm. The waterline length also increases, to 1005 cm (per a Proxi 39).



5.7.2 Mass distribution

Knowing how much a Corbin weighs is one thing, but we must also assess how the weight is distributed around the boat so as to calculate a Centre of Gravity (CG). For that we build up a table of where everything is in the boat, noting its position in x,y,z co-ordinate space, and how much it weighs. To do this we assumed a mk2 pilot house version so as to be able to estimate masts, spars, sails. Ideally in the future it will be possible to carry out an inclining test and calibrate our model to reality.

There are conceptually some main mass items which were grouped into sets as follows:

- Hull (skin, stiffeners, reinforcements)
  - Upper hull
  - Lower hull
  - Keel (GRP part)
  - Skeg-Rudder (GRP part)
- Deck – roof – cockpit(skin and structure)
- Rig, sails and deck fittings (for sails service)
- Deck/other various equipment (safety, tender, …)
- Cabin accommodation, internal equipment, motor, ...
- Ballast / Lead part
- Rudder and helm / mechanical system

For each subset one estimates the mass, Xg and Zg with the objective that the total mass is 14,000 kg and the trim is (assumed) zero which leads to an Xg of 4,505 m (this value giving zero Trim for such displacement according to the Proxi 39 loading-stability subroutine). Then, for the stability it is the Zg value which is crucial.

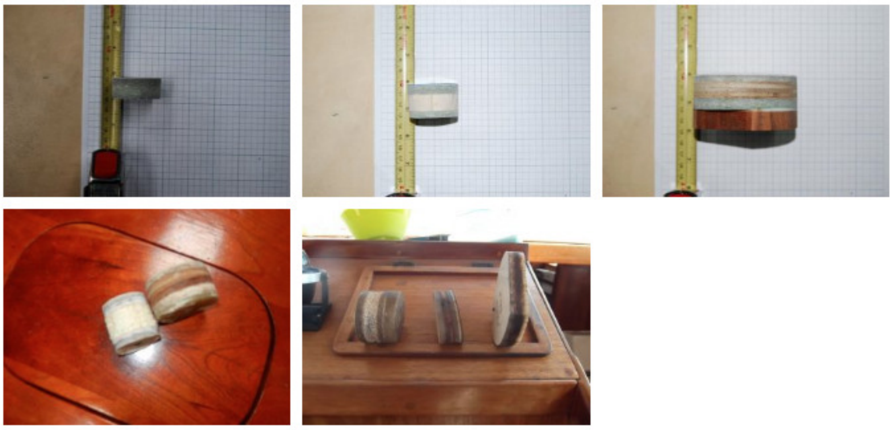
The yielded a **a Zg of 0.038 m (3.8 cm)**

In other words the Centre of Gravity of our ‘baseline’ Corbin in typical working conditions is 3.8 cm above the datum plane. The datum plane is the original Design Waterline (DWL). The summary table for this calculation is below, and the full estimation is in Appendix 4. Some comments on the assumptions made are below. The final ‘plug’ number is that of the cabin interior so as to reach the 14 tonnes objective precisely, and also so as to place the Zg position at 3.8 cm as this location is in approximate accordance with the one reference that was given by Marius Corbin.

Mass and Xg, Zg position – early stage estimation	Input data L or S or V m or m2 or m3	mass unit or % Disp.	Results Mass (kg)	Xg (m)	M Xg	Zg (m)	M Zg
Hull (skin, stiffeners, reinforcements)							
(GRP equi. Th ~ 16 mm) Upper hull	35,85	24,72	886,2	4,86	4306,99	0,65	576,04
(GRP equi. Th ~ 23 mm) Lower hull	25,24	35,15	887,1	4,57	4053,86	-0,41	-363,69
(GRP equi. Th ~30 m) Keel (GRP part)	8,27	46,50	384,6	4,93	1895,86	-1,13	-434,55
(GRP equi. Th ~ 25 mm) Skeg-Rudder (GRP part)	2,44	38,75 (kg/m2)	94,4	0,46	43,44	-0,89	-83,98
Deck – roof – cockpit(skin and structure)(Th ~26 mm)	32,53	40,27 (kg/m2)	1310,0	4,87	6379,62	1,31	1716,08
Rig, sails and deck fittings (for sails service)			625,3	5,59	3496,42	5,51	3446,48
Deck/ other various equipment (safety, tender, ...)			200,0	4,87	974,00	1,61	322,00
Cabin accomodation, internal equipment and motor			5380,1	4,22	22725,54	0,16	854,60
Ballast (Lead part)	0,35968	11350 (kg/m3)	4082,3	4,69	19129,62	-1,35	-5495,89
Rudder mechanical system			150,0	0,46	69,05	0,00	0,00
		Results : Light weight boat >>>	14000,0	4,505	63074,40	0,038	537,08

HULL & DECK CONSTRUCTION

For each of these we need to understand how much they weigh. We have photos of the various core plugs extracted by owners over the years which we can use to confirm the information in the brochures. From these we can calculate the weight per unit area of the construction in the various parts of the deck and hull.



DECK

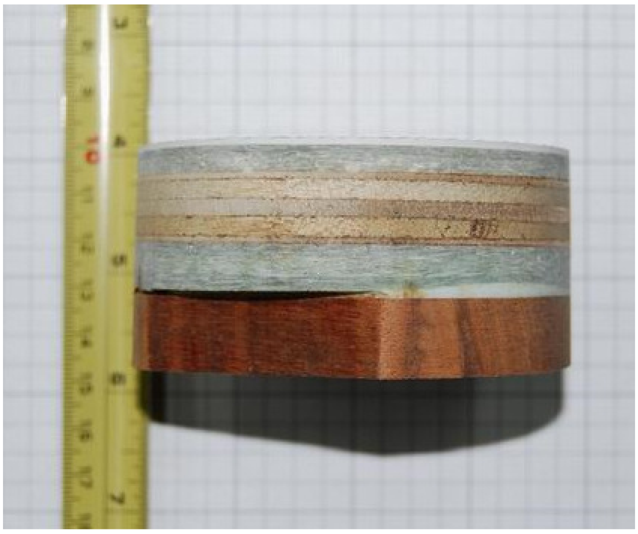
Owners report a sandwich of GRP, 1/2” (12mm) mahogany ply, and GRP, totalling 1-1/4” (32mm). This is confirmed in this photo of a deck core plug from #192, “Sarbacane”, with some mahogany backing from an interior pad. So 12mm ply and 20mm GRP arranged in a 6mm and a 14mm layer.

PLY WEIGHT: ½ ” (12mm) marine grade mahogany is 45-60 lbs per 4’ x 8’ sheet. https://www.boulterplywood.com/MarinePlywood_4.htm

GRP WEIGHT: Since it is woven mats assume SG of 1.6, i.e. 45% E-glass. https://en.wikipedia.org/wiki/Fiberglass

Total becomes 40 kg per m2.

location	material	thickness, inch	lbs per 8' x 4' sheet	sq ft per sheet	lbs per sq ft		thickness, mm	kg per sq ft	kg per m2	kg per m3
DECK	GRP upper layer (6mm)				1.97		6	0.892	9.60	1600
	1/2" (12mm) mahogany ply	0.5	52.5	32	1.64		12	0.744	8.01	668
	GRP lower layer (14mm)				4.59		14	2.081	22.40	1600
	Total weight per unit area				8.19		32	3.717	40.01	



UPPER HULL

Reportedly ¾" Airex (which would be 19mm, though 16mm is stated in the mk2 brochure) and 11 layers GRP (inc 4 layers woven roving). From the photo of a core plug taken from #192, "Sarbacane", the total thickness is 31mm comprising 10mm outer GRP, 16mm Airex, and 5mm inner GRP.

The Airex in question is most likely the R63 grade which is a damage tolerant foam intended for marine applications. It is part-sliced into blocks to facilitate laying around curves and to allow resin securing. Density is 60kg/m3.

This was carried down to just below the turn of the bilge at least in the centre section. In the stern and bow it may have terminated at the waterline.

Total is 25kg/m2.

UPPER HULL	GRP outer layer				3.28		10	1.486	16.00	1600
	Airex R63 (16mm)				0.20		16	0.089	0.96	60
	GRP inner layer				1.64		5	0.743	8.00	1600
	Total weight per unit area				5.11		31	2.319	24.96	

LOWER HULL

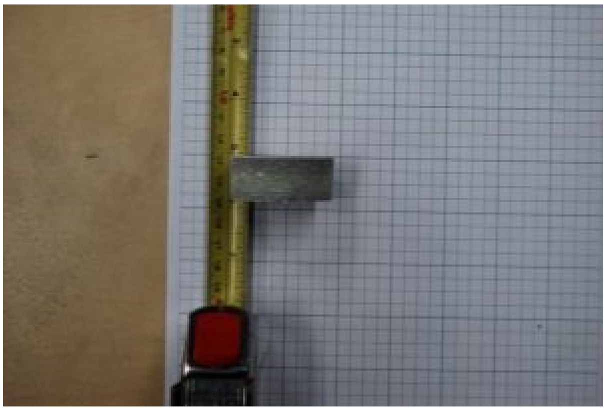
0.5mm gelcoat.

Keel side and turn of bilge 21 layers GRP (inc 10 layers 24oz woven roving).

Along centreline 25 layers GRP (inc 12 layers 24oz woven roving).

Along centreline 35 layers GRP (inc 16 layers woven roving).

Total is 20mm thick from the photo of a core plug taken from #192, “Sarbacane”,



Total becomes 32 kg per m2.

location	material	thickness, inch	lbs per 8' x 4' sheet	sq ft per sheet	lbs per sq ft	lbs per layer	area, sq ft		thickness, mm	kg per sq ft	kg per m2	kg per m3	kg per layer
LOWER HULL	GRP outer layer				6.55	1,877			20	2.973	32.00	1600	851
exc keel & rudder	-				0.00	-				0.000	0.00		0
	-				0.00	-				0.000	0.00		0
	Total weight per unit area				6.55	**1,877**	286		20	2.973	32.00	1,600	**851**

Total hull should exceed 4,000 lbs inc Airex according to a Corbin marketing claim.

KEEL BALLAST

Lead, approx 9,000 lbs – 9,200 lbs placed in lower keel and encapsulated in resin. Some were lead shot, some lead ingots, and some were moulded plugs. Then 8 layers (4 mats, 4 rovings) of fibreglass were laid on top.

Assume 11.34 g/cm3 for pure lead. Lead shot would be approx 7g/cm3. Cast with impurities would typically be approx 11g/cm3.

Decision >> assume 11g/cm3. **Decision** >> assume 9,000 lbs = 4,082 kg.

Various other items are detailed in Appendix 4.

5.8 Analyse static longitudinal trim and draught

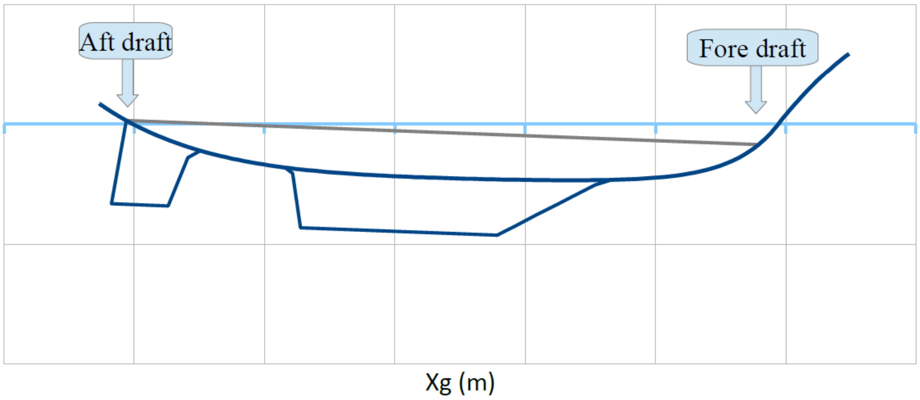
With the measurements of the Fore and Aft drafts (when the boat at mooring on flat sea) with reference to the waterline of the original linesplan, it is possible to recover the displacement D, the longitudinal position of the center of gravity (Xg) and of course the trim. This approach (presently based on the hull geometry of Proxi 39), is proposed in a spreadsheet application.

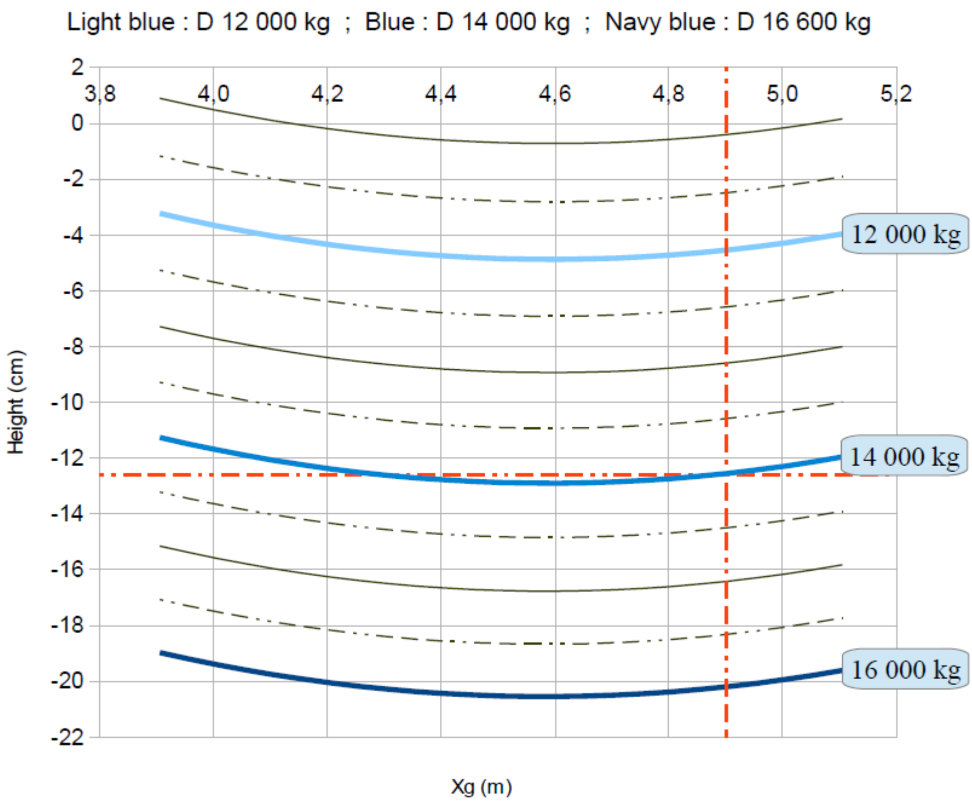
Appendix 5 contains the trim and draught spreadsheet as .ods file for Open Office / Libre Office. It will also function in Microsoft Excel.

Example :

Input data		Output data		
Aft draft STA 10 (cm)	**Fore draft** STA 0 (cm)	**>> Trim** (°)	**>> Height** (cm)	**>> Xg** (Center of gravity) (m)
6,0	**-34,0**	**-2,36**	**-12,6** (sinking at X 4,52 m)	**4,901**

>>> Automatical drawings :





>>> Result of this example : Displacement 14 000 kg (the crossing of the red lines) at Xg 4,901 m, generating a trim of – 2,36°

5.9 Analyse static transverse stability

Once all the above preparatory work has been done, then the main issue can be assessed : how stable is the boat ? This stability issue has been addressed by Gene-Hull and Multisurf and DelftShip+ArchimedesMB all on the same basis. With the following assumptions, resulting from the above analysis, the results of all three are in good agreement.

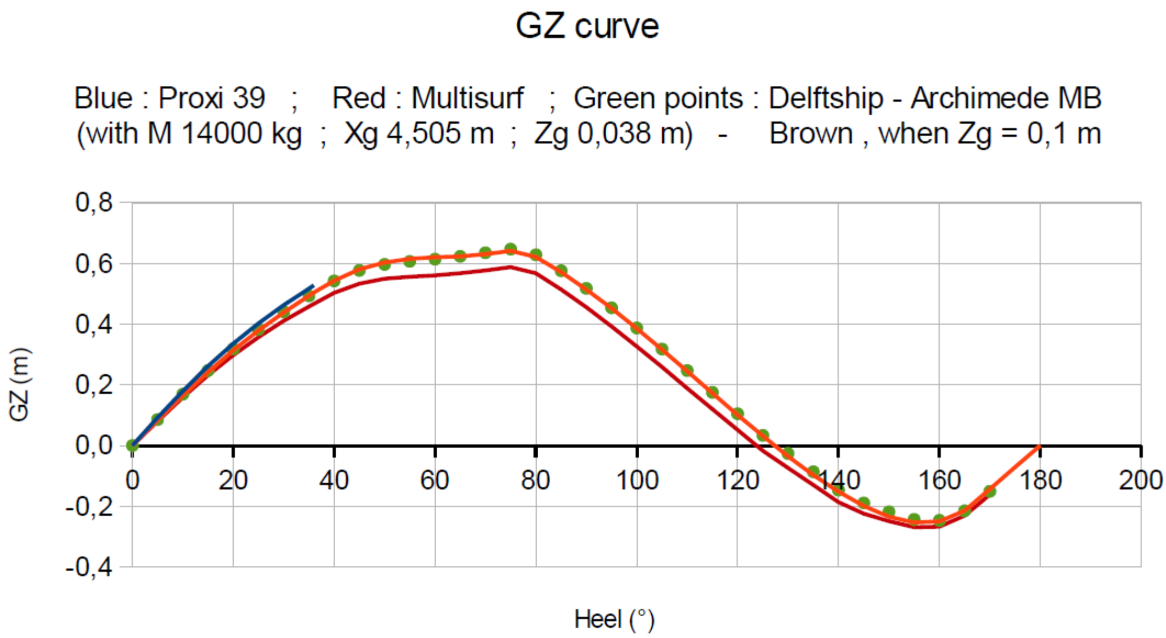
Assumptions for this study :

- a displacement of **14000 kg** assumed to be the minimum weight of the existing boats
- **a trim = 0° for this displacement,** which assumes that the owners can organise the mass arrangement for this objective. This zero trim is **obtained with Xg = 4,505 m.**
- **a Zg = 0,038 m** resulting from the mass spreadsheet (with mk2 sailplan)

Results (and in Annex 6 the output data) :

>>> GMt : (as computed at 1° Heel) >>> 1,06 m Gene-Hull
>>> 0,98 m Multisurf
>>> 0,99 m Delfship-Archimede MB

>>> GZ curve :



At heel angle 36° (end of the blue line) **starts the immersion of the sheer line**. The angle of vanished stability **AVS is 127°.** The positive area up to 127° is 51,8 deg.m. The negative area from 127° to 180° is -8,2 deg.m >>> **Area ratio is 6,3** > 5 .

The associated video of a Corbin 39 heeling from 0-degrees (upright) to 180-degrees (inverted) is available online:
https://www.youtube.com/watch?v=h0AngYDBMIQ&feature=youtu.be

>>> GZ curve sensitivity

An issue is the sensitivity of the GZ curve to Zg, i.e. if an owner is placing weight higher in the boat. Three examples of this are:

- When assuming the sub-system [Rig-sails] with 625 kg placed higher by 0,5 m this would increase Zg >>> **Zg 0,061 m**

- When assuming the 200 kg provision of [others] on the deck be increased to 300kg and be higher by 0,5 m (at 2,11 m) >>> **Zg 0,059 m**
- When assuming the 5380 kg of the [cabin accomodation, internal Equipment, motor, …] be 0,14 m higher (at 0,30 m instead of 0,16 m) >>> **Zg 0,092 m**

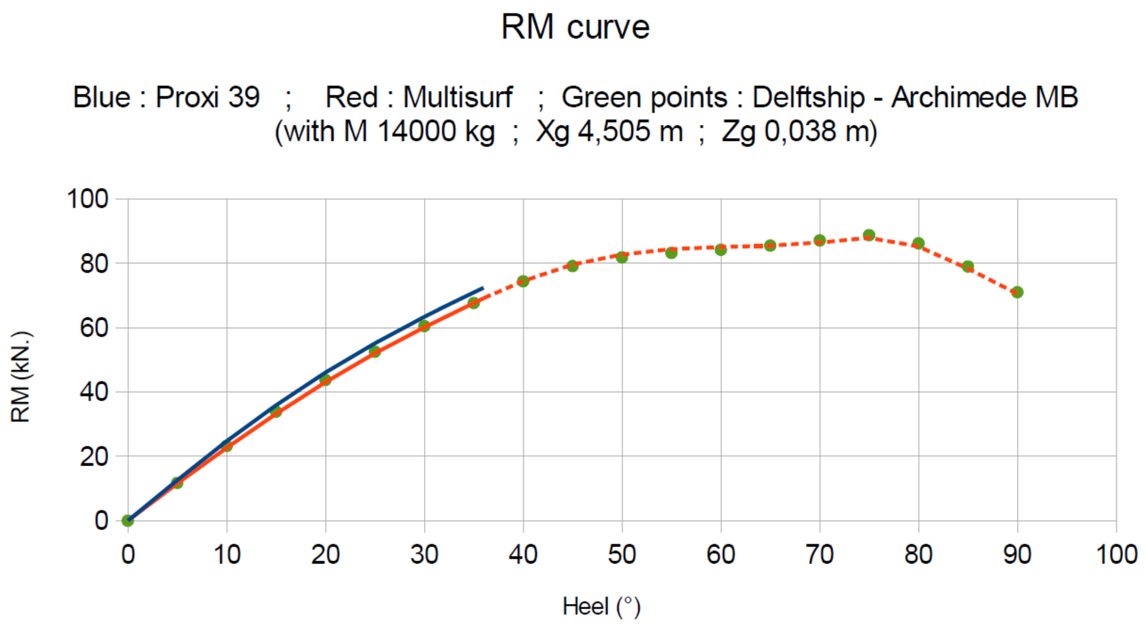
Therefore we recommend that a single class boat be fully measured regarding these weights, and the centre of mass (by an inclining test) so as to document as much as possible the actual class norms vs these assumptions (the motor, etc… i.e. the Z position of all the weights which are quite heavy). In the meantime we assess a case where we hope the resulting center of gravity position would not overshoot Zg = 0,1 m at the worst. So we also add this curve (the brown dashed line) in the GZ chart above.

>>> With Zg = 0,1 m assumption, the AVS becomes 123,8° and the areas ratio 4,94.

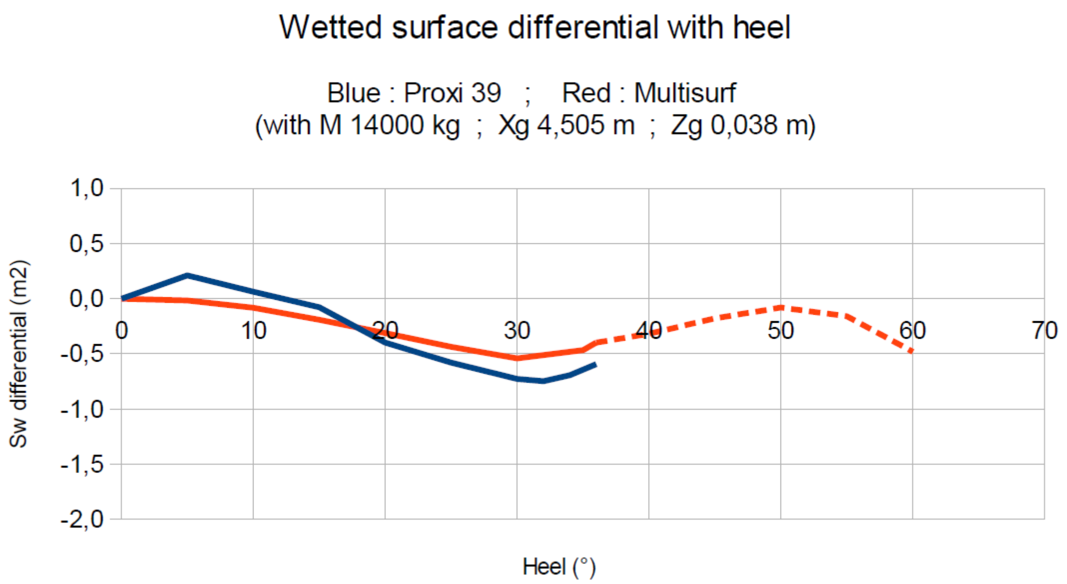
<u>>>> The Righting Moment RM :</u> RM30° = 60,2 kN.m (Multisurf)

60,5 kN.m (Delfship – Archimede MB)

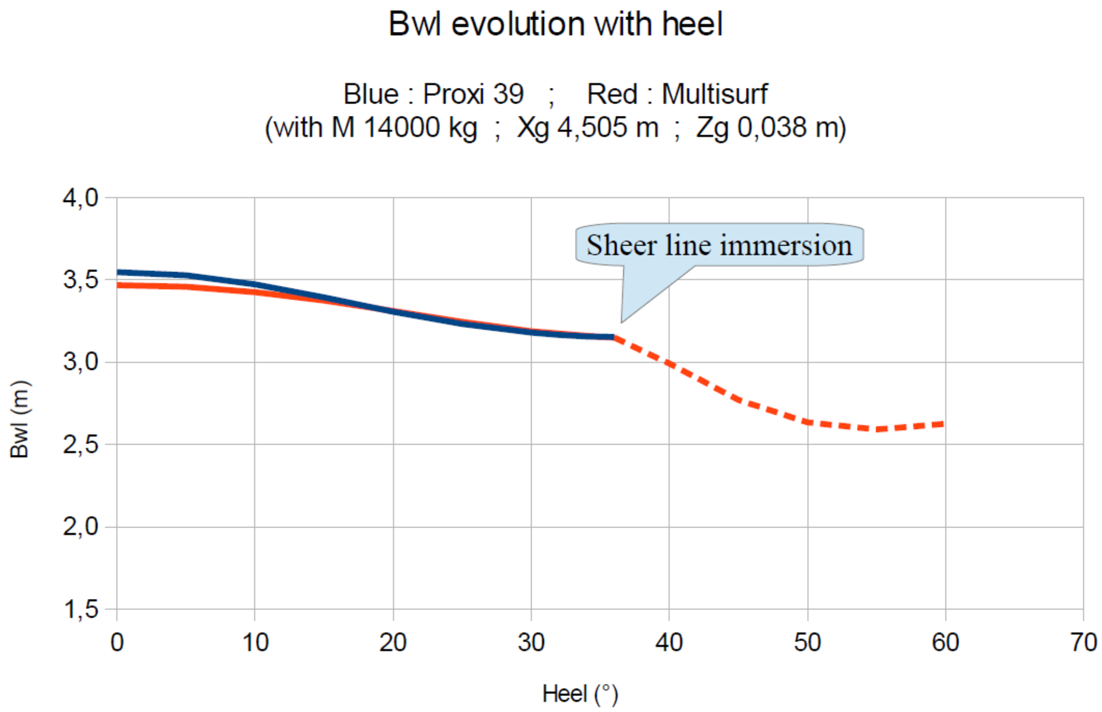
63,4 kN.m (Gene-Hull)



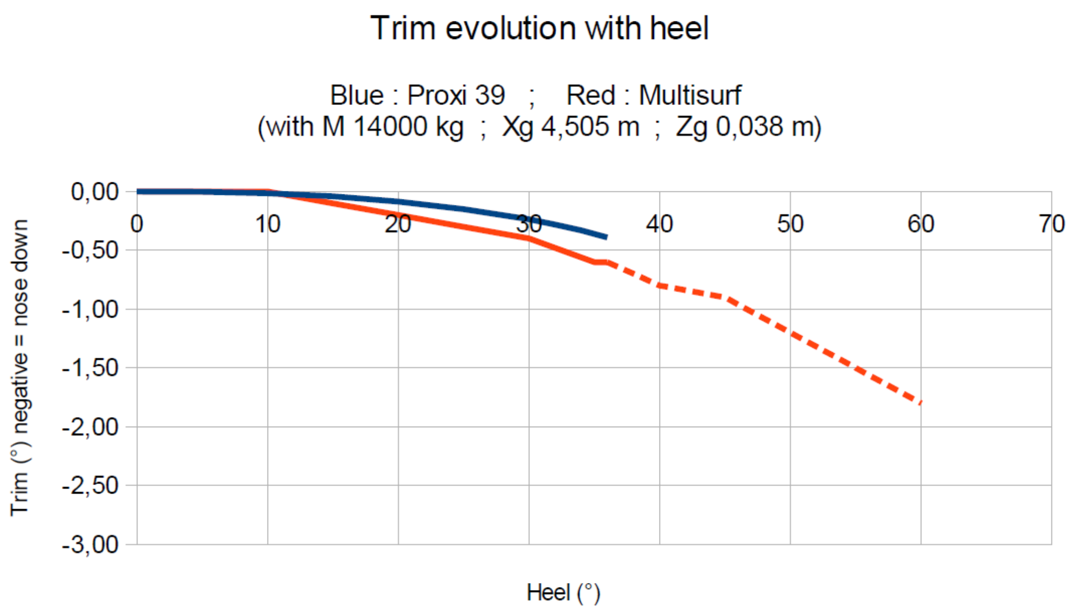
<u>>>> The wetted surface Sw evolution :</u>



>>> The Bwl evolution

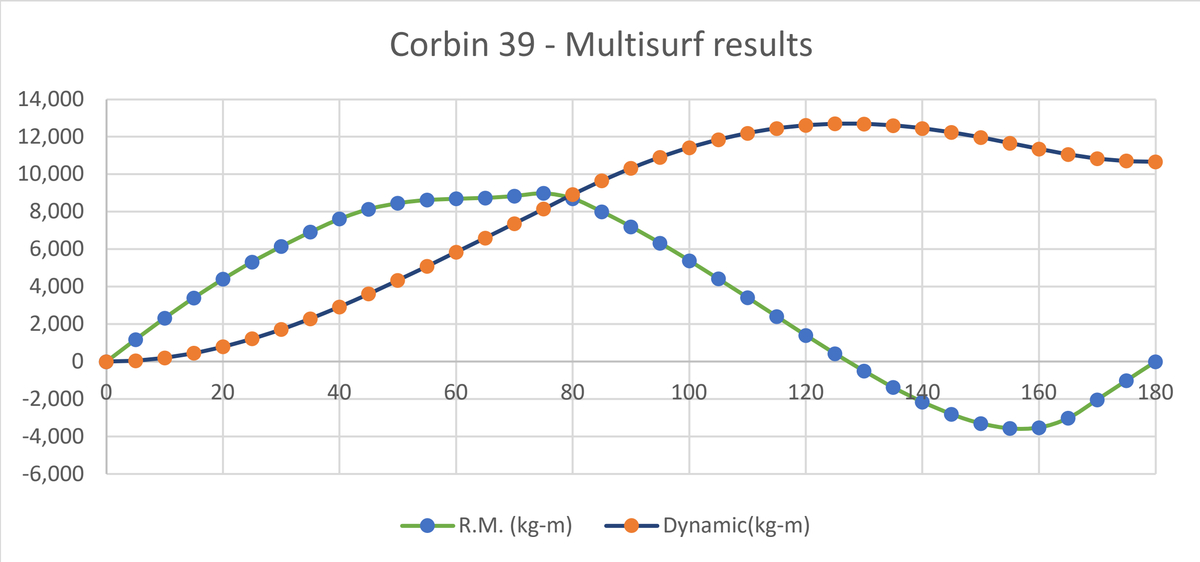


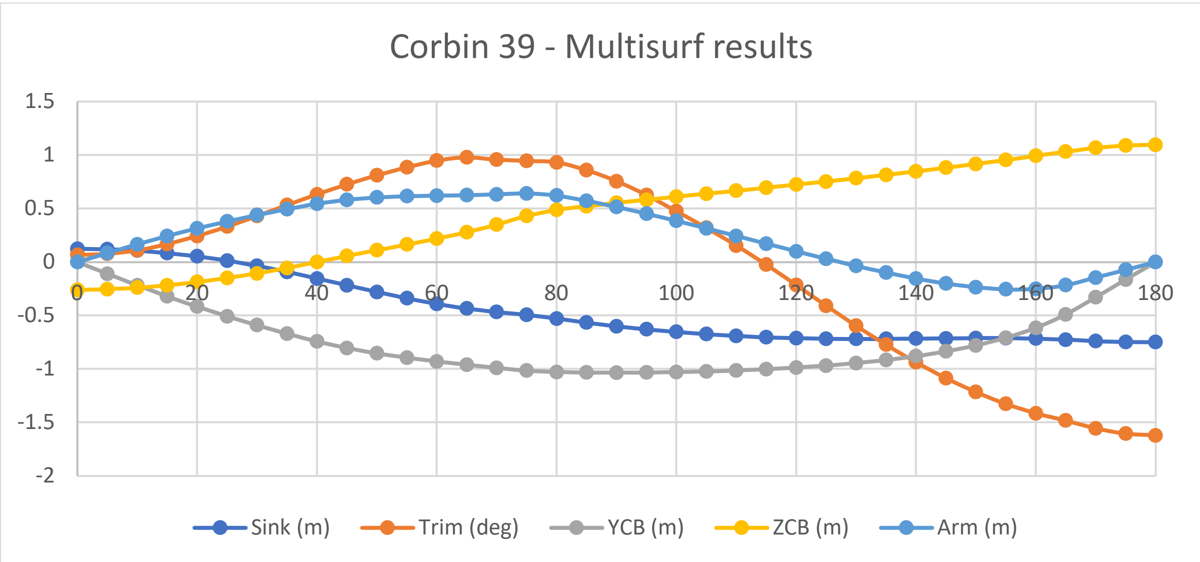
>>> The trim evolution (negative = bow down)



>>> Collected results from MultiSurf

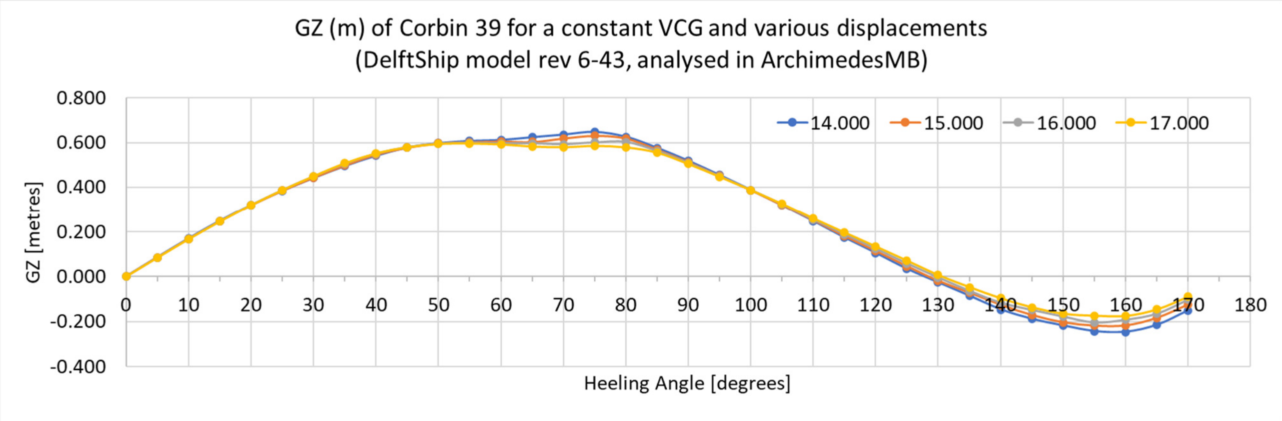
Here are the collected results from Multisurf



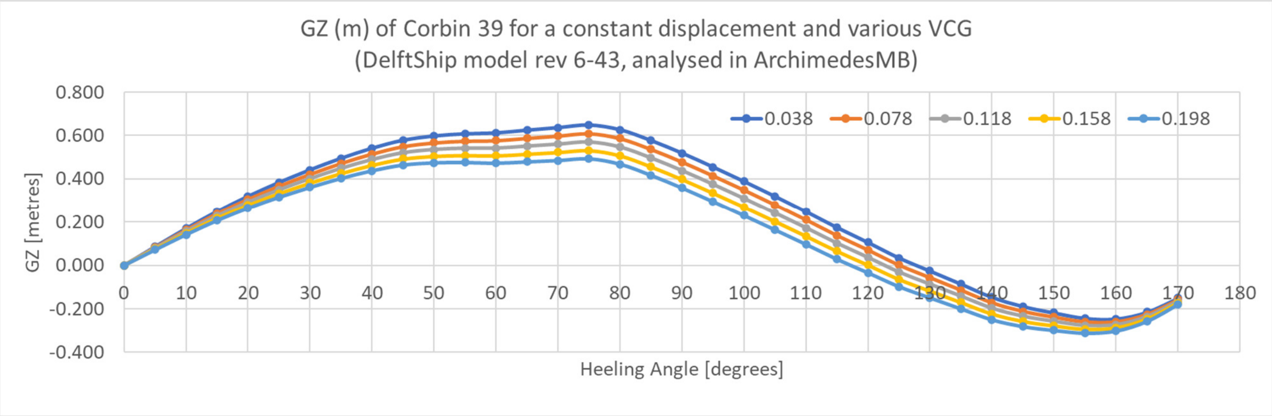


>>> Collected results from DelftShip combined with ArchimedesMB

Note that the GZ curves below for a range of displacements are rather misleading as they assume that GG remains constant even as the boat is more heavily laden. The reality is that unless the additional mass is positioned at, or below, the level of VCG = 3.8 cm then the boat will become more unstable.



The same analysis, but this time for a constant displacement and several VCG. As you would expect stability reduces as VCG increases in height.



6 Recommendations

The two largest assumptions in this analysis are the actual weight of a typical Corbin in its as-built condition, and the associated position of the Centre of Gravity. Given that the hulls are all moulded the same (although one or two have had subsequent underwater modifications), it is worth the effort to resolve this.

1. For a boat with no underwater modifications and a known keel ballast of ideally either 9,000 lbs or 9,200 lbs bring it to a well-documented condition (ideally, but not necessarily, lightship) and then:
    a. Weigh it carefully (e.g. per IRC / ORC), ideally in lightship condition;
    b. Measure it carefully for the hull, both wet and dry (e.g. per IRC/ORC);
    c. Document the mast & spars & sails (but not necessarily measure them);
    d. Carry out an inclining test (e.g. per IRC/ORC);
    e. Refill it to a documented normal operating condition, and carefully note what was entered into the boat, where it went, and the resulting draught (or even weight it again if possible).
2. For other boats collect all possible available data on weight, condition, and draught.
3. Refine the analysis set out here to reduce errors and give clearer information.

7 Appendixes

Appendix 1 : Comparison of digital dimensional models

Appendix 2 : DelftShip - Lines plan and basic data

Appendix 3 : MultiSurf – Lines Plan and basic data

Appendix 4 : The mass spreadsheets

Appendix 5 : The Gene-Hull trim and draught spreadsheet

Appendix 6 : The Gene-Hull full stability results

Appendix 7 : The ArchimedesMB output spreadsheets for various tonnages, and various Zg

Appendix 8 : Multisurf Results