

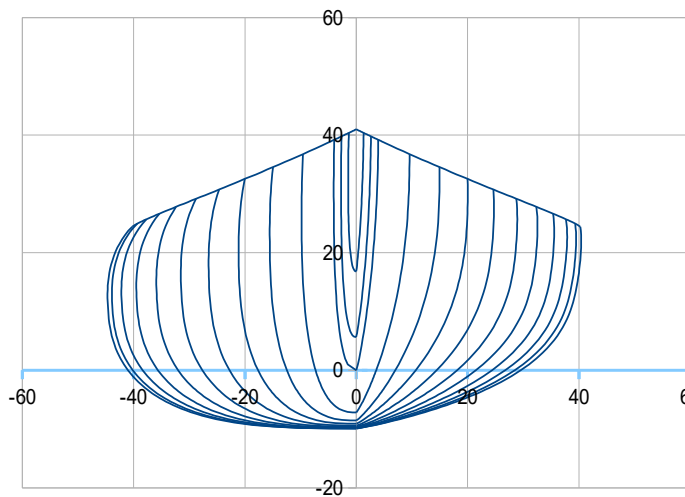
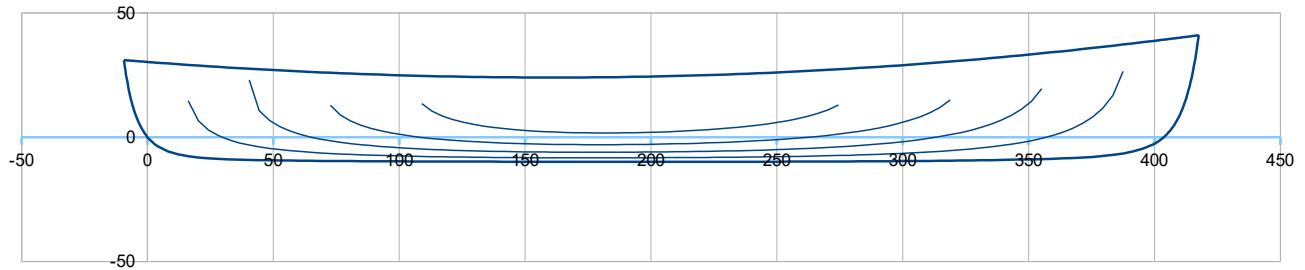
Solo style Canoe with an asymmetric hull
preliminary design (version V1) - stability issue and comparison

Loa 4,27 m (14') Boa 0,85 m (33,54") Bsheer 0,81 m (31,89")

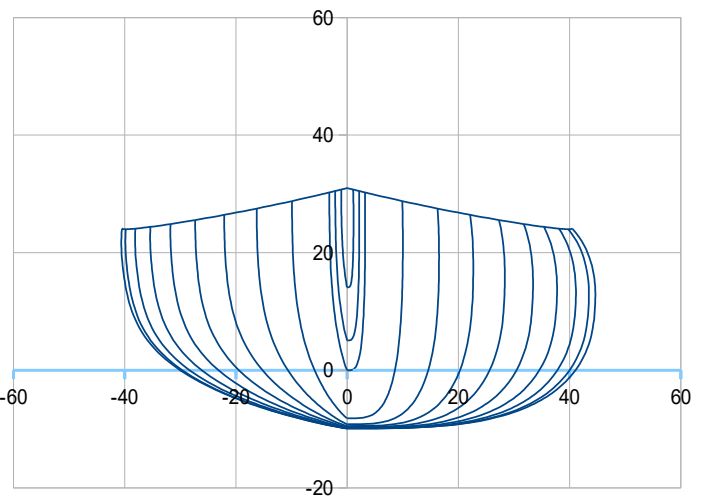
At design waterline, for a displacement of 122 kg (light weight 22 kg + loading 100 kg) :

Lwl : 4,04 m (13,24") Bwl : 0,711 m (28") Tc : 0,099 m (3,89")

Starboard half-beam 0,411 m (16,20") ; Port half beam : 0,300 m (11,81")



View from front

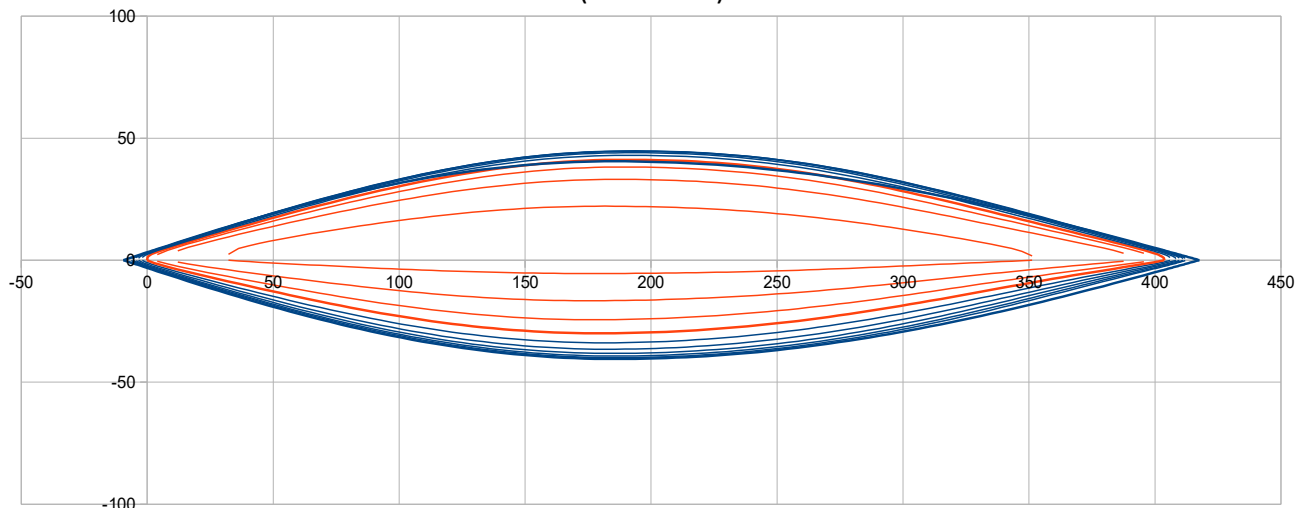


View from rear

Aft

View from Bottom
(Starboard)

Fore



(Port)

Hydrostatics (at design waterline) :

Half Hull Port

Loa (m)	4,27	Lwl (m)	4,04						
>> ft	14,01	>> ft	13,24						
½ Bsheer (m)	0,405	at X (% Lwl)	46,0	½ Bmax (m)	0,406				
>> inch	15,94			>> inch	15,99				
½ Bwl (m)	0,300	at X (% Lwl)	45,0	> Bwl / B	0,741				
>> inch	11,81			Freeboards (m) >		Aft	Midship	Fore	
Tc (m)	0,099	at X (%Lwl)	50			0,31	0,24	0,41	
>> inch	3,89				>> inch	12,20	9,45	16,14	
½ Displacement at wl (m3)	0,04337	at Xc (m)	1,907	Xc (%Lwl)	47,24		Zc (m)	-0,036	
(kg)	43,4	>> ft	6,26				>> inch	-1,40	
>> lbs	95,6	with water mass / vol. of	1000		kg/m3		Yc (m)	-0,086	
Cp	0,599						>> inch	-3,41	
½ Sf (m2)	0,75	at Xf (m)	1,923	Xf (%Lwl)	47,63	>>> Xc – Xf (%Lwl)		-0,39	
>> ft2	8,12	>> ft	6,31						
½ Sw (m2)	0,85								
>> ft2	9,19								
½ Shull (m2)	2,13	at X (m)	2,060	Z (m)	0,059	Y (m)	-0,186		
>> ft2	22,94	>> ft	6,76	>> inch	2,32	>> inch	-7,34		

Half Hull Starboard

Loa (m)	4,27	Lwl (m)	4,04						
>> ft	14,01	>> ft	13,24						
½ Bsheer (m)	0,405	at X (% Lwl)	46,0	½ Bmax (m)	0,447				
>> inch	15,94			>> inch	17,59				
½ Bwl (m)	0,411	at X (% Lwl)	47,0						
>> inch	16,20			Freeboards (m) >		Aft	Midship	Fore	
Tc (m)	0,099	at X (%Lwl)	50,0			0,31	0,24	0,41	
>> inch	3,89				>> inch	12,20	9,45	16,14	
½ Displacement at wl(m3)	0,08173	at Xc (m)	1,957	Xc (%Lwl)	48,47		Zc (m)	-0,042	
(kg)	81,7	>> ft	6,42				>> inch	-1,67	
>> lbs	180,2	with water mass / vol. of	1000		kg/m3		Yc (m)	0,137	
Cp	0,623						>> inch	5,39	
½ Sf (m2)	1,07	at Xf (m)	1,980	Xf (%Lwl)	49,05	>>> Xc – Xf (%Lwl)		-0,58	
>> ft2	11,53	>> ft	6,50						
½ Sw (m2)	1,19								
>> ft2	12,80								
½ Shull (m2)	2,41	at X (m)	2,060	Z (m)	0,036	Y (m)	0,217		
>> ft2	25,91	>> ft	6,76	>> inch	1,43	>> inch	8,55		

Full Hull

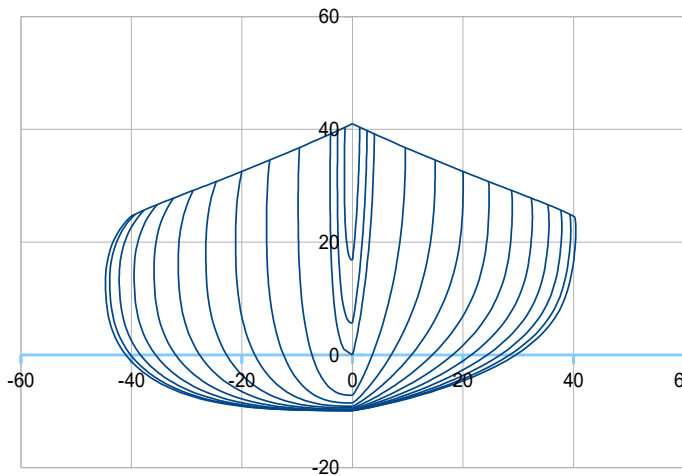
Loa (m)	4,27	Lwl (m)	4,04						
>> ft	14,01	>> ft	13,24						
Bsheer (m)	0,81	at X (% Lwl)	46,0	Bmax (m)	0,85				
>> inch	31,89			>> inch	33,58				
Bwl (m)	0,711	> Lwl / Bwl	5,68	Bwl / Bsheer	0,878				
>> inch	28,01								
Tc (m)	0,099	at X (%Lwl)	50,0	> Bwl / Tc	7,19	Freeboards (m) >	Aft	Midship	Fore
>> inch	3,89				>> inch		0,31	0,24	0,41
							12,20	9,45	16,14
Displacement at H0 (m3)	0,12511	at Xc (m)	1,939	Xc (%Lwl)	48,04		Zc (m)	-0,040	
(kg)	125,1	>> ft	6,36				>> inch	-1,58	
>> lbs	275,8	with water mass / vol. of		1000	kg/m3		Yc (m)	0,059	
							>> inch	2,34	
Cp	0,614								
Sf (m2)	1,83	at Xf (m)	1,956	Xf (%Lwl)	48,46	>>> Xc – Xf (%Lwl)		-0,42	
>> ft2	19,65	>> ft	6,42						
Sw (m2)	2,04	>Sw/D^(2/3)	8,17						
>> ft2	21,99								
Shull (m2)	4,54	at X (m)	2,060	Z (m)	0,047	Y (m)	0,028		
>> ft2	48,85	>> ft	6,76	>> inch	1,85	>> inch	1,09		

The center of buoyancy is reported in Y of 5,9 cm while the center of hull weight is reported of 2,8 cm.

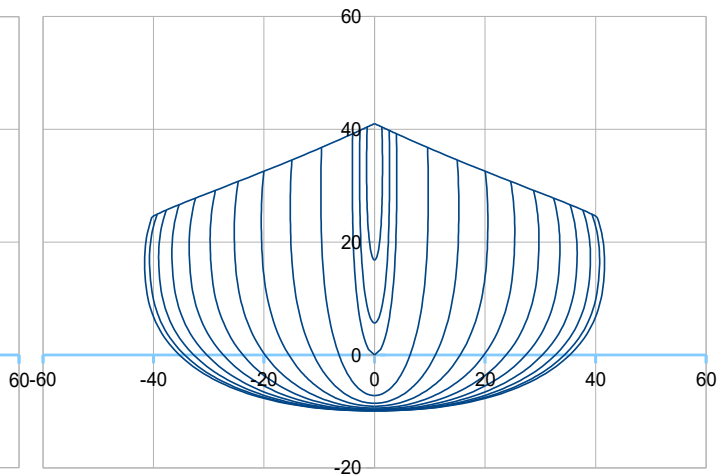
The stability issue

To better illustrate the asymmetric option, the stability study is carried out with including a comparison with its symmetrical equivalent at same LoA, Keel line, Sheer line (beam and free boards), weight and waterline beam at design displacement (0,711 m / 28") :

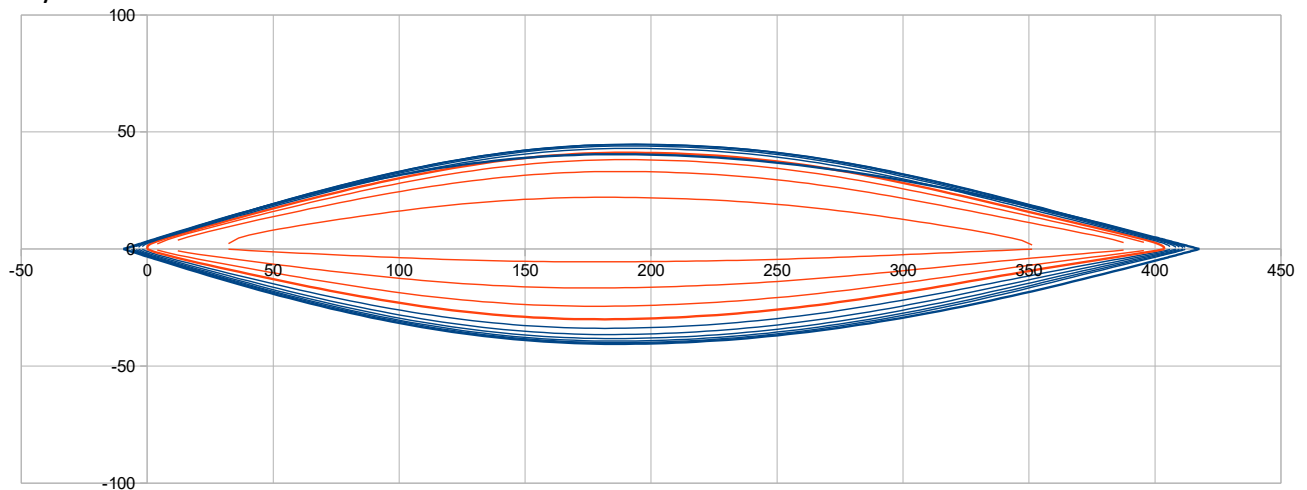
Asymetric hull



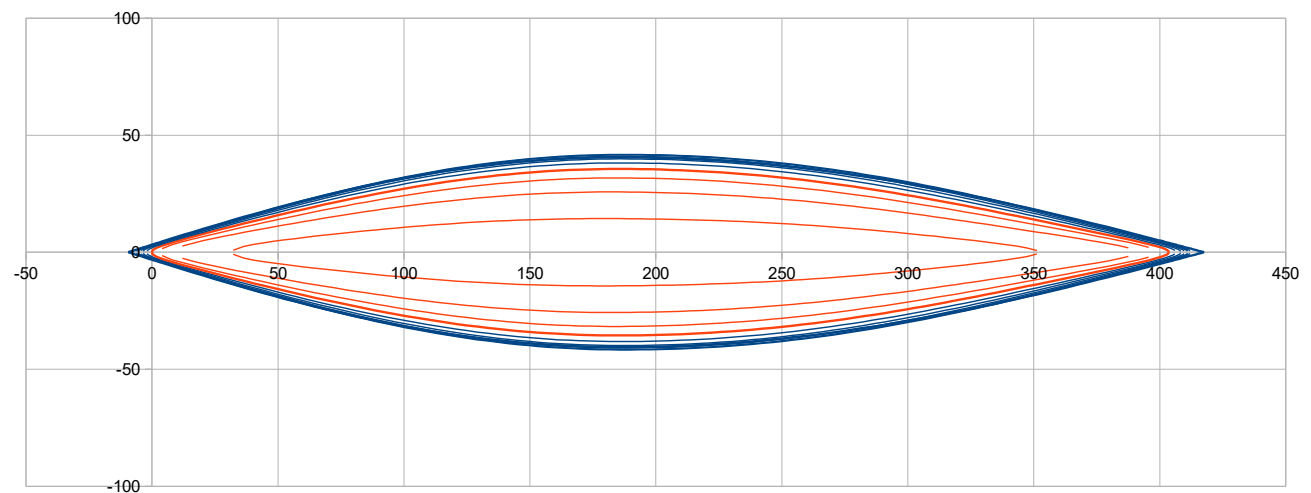
Symetric hull (at same D, Bwl , etc...)



Asymetric hull



Symetric hull



1. Equilibrium without loading >>> Displacement = Light weight canoe = 22 kg

Asymetric : $GZ = 0 \gg$ Heel $5,56^\circ$

Symetric : $GZ = 0 \gg$ Heel 0°

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,85	22,0	2,060	0,047
Paddler (kg) >	0,0	0,000	0,00	0,000
Camping equipment (kg) >	0,0	0,000	0,00	0,000
M tot (kg)	22,0	2,060	0,047	-0,028
> Disp. (m3)	0,02201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacer

Data to enter (yellow cases)

Heel ($^\circ$)	-5,56
Height (cm)	6,3850

Results

From the Hull :

> Disp. (m3)	0,02201	From the Mass :	0,02201
Xc (m)	1,899	Ym (m)	-0,0230
Yc (m)	-0,0230	> GZ (cm)	0,00
Zc (m)	-0,012	> RM (N.m)	0,00
> Sw (m2)	1,137	FB mini (cm)	26,4

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,86	22,0	2,061	0,045
Paddler (kg) >	0,0	0,000	0,00	0,000
Camping equipment (kg) >	0,0	0,000	0,00	0,000
M tot (kg)	22,0	2,061	0,045	0,000
> Disp. (m3)	0,02201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacer

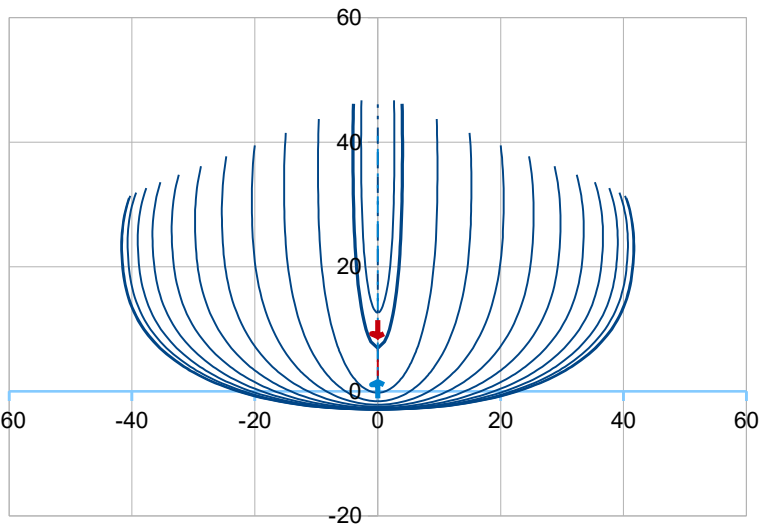
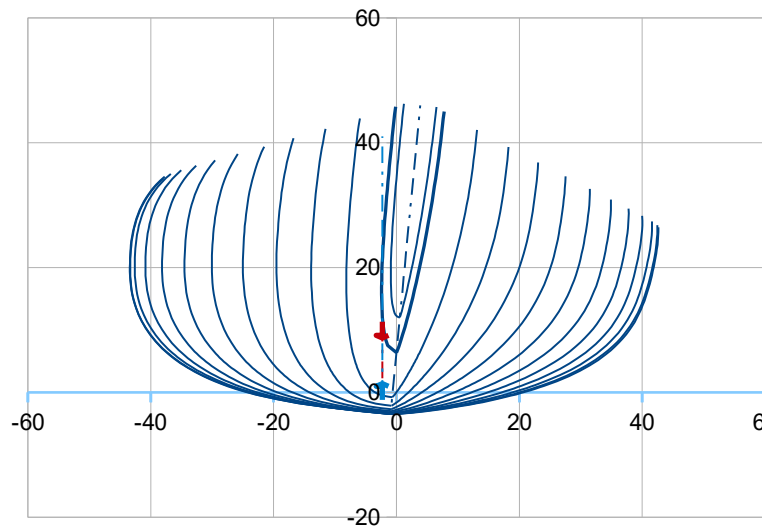
Data to enter (yellow cases)

Heel ($^\circ$)	0,00
Height (cm)	6,9350

Results

From the Hull :

> Disp. (m3)	0,02201	From the Mass :	0,02201
Xc (m)	1,905	Ym (m)	0,0000
Yc (m)	0,0000	> GZ (cm)	0,00
Zc (m)	-0,011	> RM (N.m)	0,00
> Sw (m2)	1,169	FB mini (cm)	30,9



>>> the asymetric shows just $5,56^\circ$ of heel angle and the freeboard mini (on port side) is 26,4 cm

2. Equilibrium with a paddler 80kg decentering at Y cm on the starboard side / keel axis

We assume that the paddler can maintain the trunk of his body approximatively vertical whatever the boat heel angle in the usual range ($\pm 20^\circ$), as a basic instinct to maintain his stability (this can be seen on the videos). So, for the stability computation, that means a body weight vector origin (i.e. the pivoting point of this compensation) slightly above the bench. Here we assume that such point is at **Z = 20 cm**.

Y is here set at **7,1 cm** because that corresponds to the upright equilibrium for the asymmetric case, and also because such Y decentering gives an heel angle of about 16° for the symmetric case, the kind of angle that can be seen on the videos.

Asymmetric : $GZ = 0$ for Heel = 0°

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,85	22,01	2,060	0,047
Paddler (kg) >	80,00	1,900	0,20	-0,0713
Camping equipment (kg) >	0,00	0,000	0,00	0,000
M tot (kg)	102,0	1,934	0,167	-0,062
> Disp. (m3)	0,10201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacement

Data to enter (yellow cases)	Results
Heel ($^\circ$) 0,00	From the Hull : > Disp. (m3) 0,10201
Height (cm) 1,3085	From the Mass : / Disp. (m3) 0,10201
	Xc (m) 1,936 Ym (m) -0,0619
	Yc (m) -0,0619 > GZ (cm) 0,00
	Zc (m) -0,034 > RM (N.m) 0,03
	> Sw (m2) 1,901 FB mini (cm) 25,3

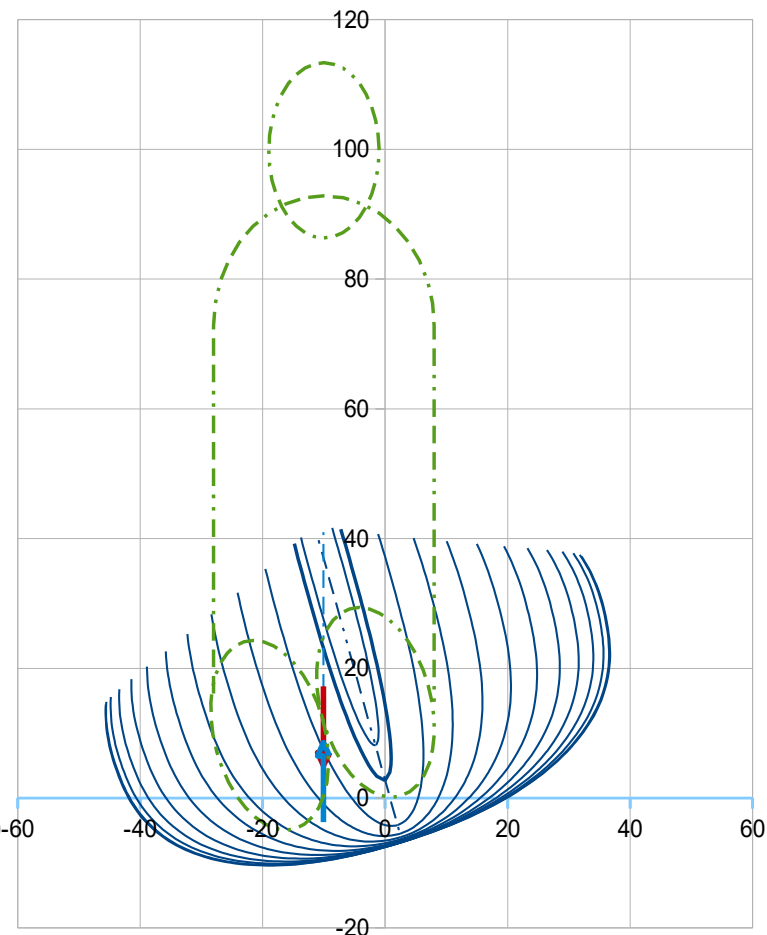
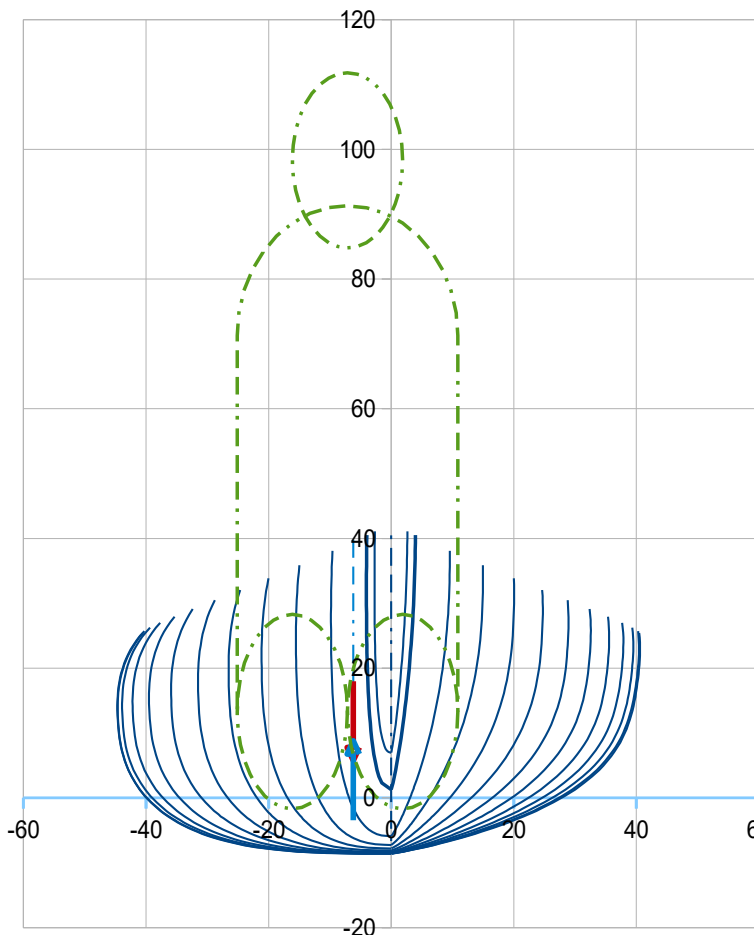
Symmetric : $GZ = 0$ for Heel = $16,35^\circ$

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,86	22,01	2,061	0,045
Paddler (kg) >	80,00	1,900	0,20	-0,0713
Camping equipment (kg) >	0,00	0,000	0,00	0,000
M tot (kg)	102,0	1,935	0,167	-0,056
> Disp. (m3)	0,10201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacement

Data to enter (yellow cases)	Results
Heel ($^\circ$) 16,35	From the Hull : > Disp. (m3) 0,10201
Height (cm) 2,8320	From the Mass : / Disp. (m3) 0,10201
	Xc (m) 1,940 Ym (m) -0,1005
	Yc (m) -0,1006 > GZ (cm) 0,00
	Zc (m) -0,037 > RM (N.m) 0,02
	> Sw (m2) 1,822 FB mini (cm) 14,5

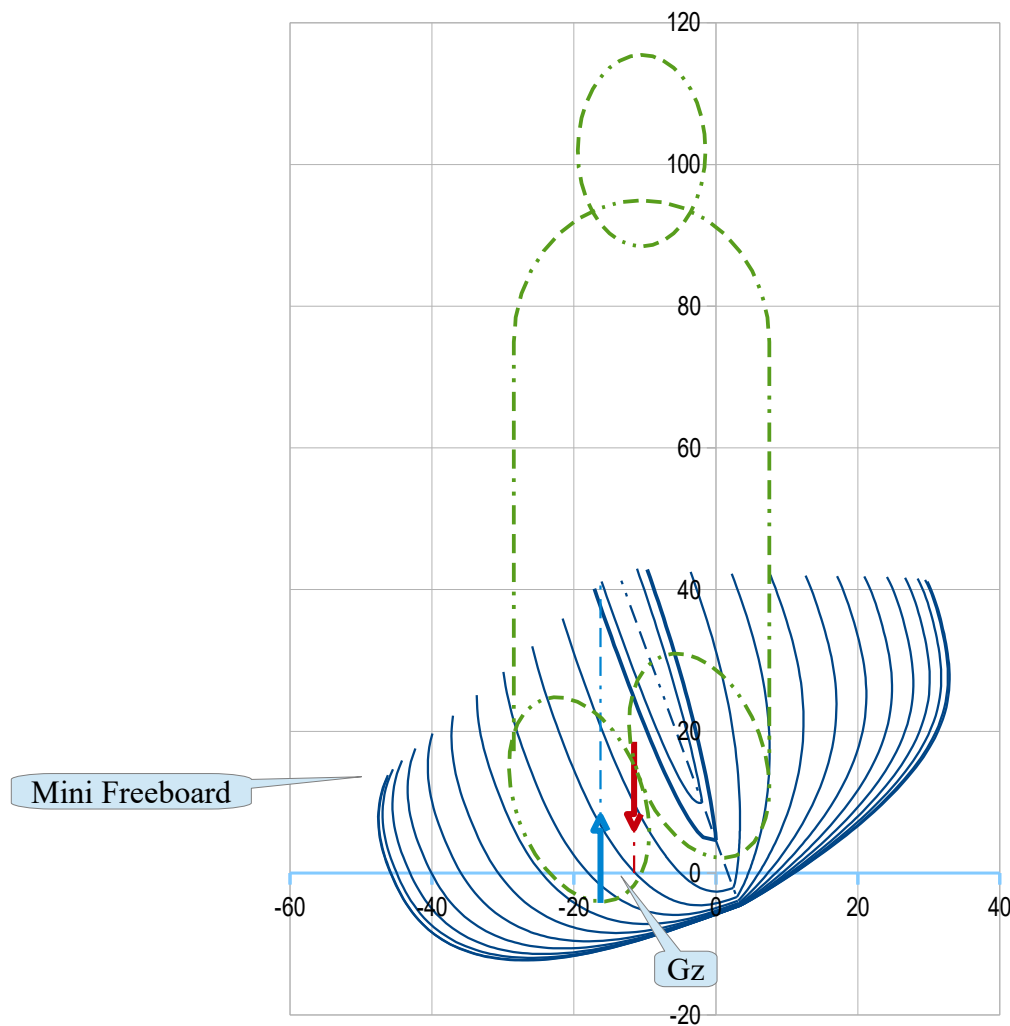


Although the asymmetric is still upright, the symmetric is already at heel 16,35° because the body weight pivoting point is slightly deformed on starboard (here of about 4 cm, see the Ym values) whatever the paddler effort to maintain his trunk vertical, and that accentuates the heel angle. As a consequence, the minimum free-board is reduced to 14,5 cm.

3. GZ curve and freeboard evolution with heel angles around the equilibrium

For any heel angle outside the equilibrium, two dangers are to be feared : the lack of restoring moment, the lack of freeboard preventing from water intake. The GZ value (i.e. the lever arm between the buoyancy vector and the total weight vector) gives the restoring capacity (\gg the righting moment $RM = GZ \times \text{Weight}$), and the minimum freeboard value informs on the risk of water intake. We check these 2 parameters with an heel angle variation up to at least $\pm 20^\circ$ on both sides (as the results are different), and still assuming that the paddler has the ability to maintain his body trunk \sim vertical.

The asymmetric case, at heel 20° on starboard side :



The GZ of 4,7 cm leads to a righting moment $RM = 4,8 \text{ kg.m}$. The minimum freeboard is 13,5 cm

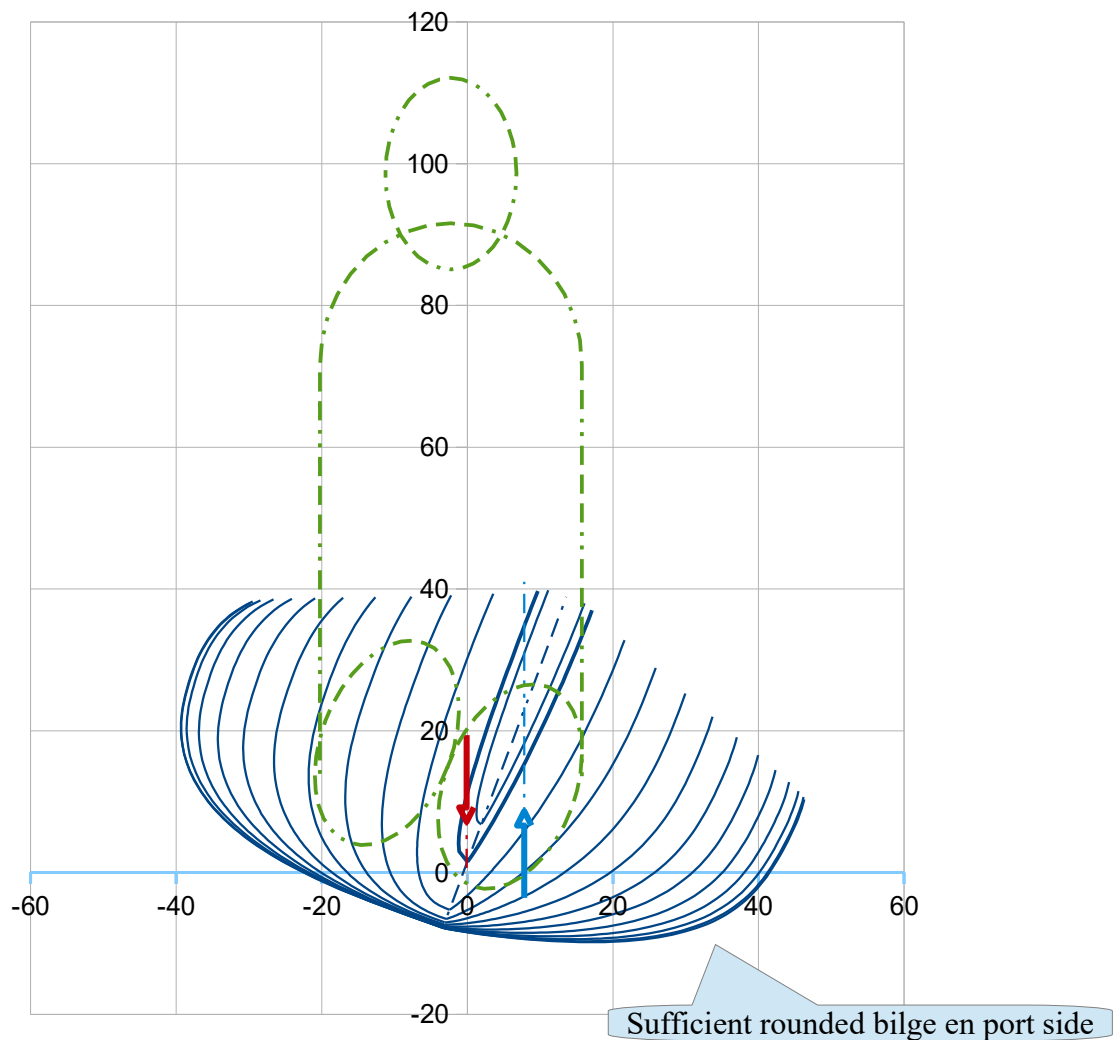
6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg/m2)	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,85	22,01	2,060	0,047	-0,028
Paddler (kg) >		80,00	1,900	0,20	-0,0713
Camping equipment (kg) >		0,00	0,000	0,00	0,000
M tot (kg)		102,0	1,934	0,167	-0,062
> Disp. (m3)		0,10201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacemer

Data to enter (yellow cases)	Results
Heel (°) 20,00	From the Hull : > Disp. (m3) 0,10201
Height (cm) 4,9470	From the Mass : / Disp. (m3) 0,10201
	Xc (m) 1,949 Ym (m) -0,1153
	Yc (m) -0,1626 > GZ (cm) 4,73
	Zc (m) -0,042 > RM (Kg.m) 4,82
	> Sw (m2) 1,696 FB mini (cm) 13,5

The asymmetric case, at heel 20° on port side :



The GZ of 7,9 cm leads to a righting moment RM = 8,1 kg.m : the RM is higher due to the fact that the paddler is sit on the starboard side, and the shape of the port side sections has sufficient rounded bilge to not alter the RM. The minimum free-board is reduced to 10,3 cm.

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

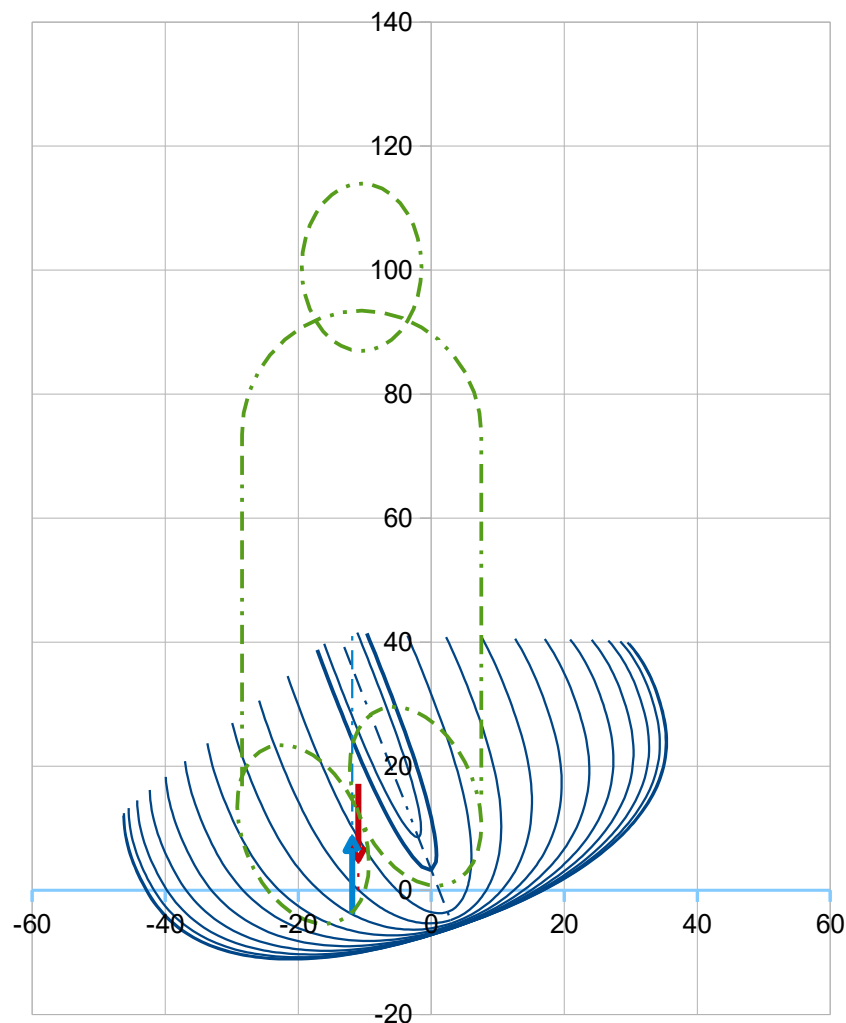
	(kg/m ²)	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,85	22,01	2,060	0,047	-0,028
Paddler (kg) >		80,00	1,900	0,20	-0,0713
Camping equipment (kg) >		0,00	0,000	0,00	0,000
M tot (kg)		102,0	1,934	0,167	-0,062
> Disp. (m3)		0,10201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacer

Data to enter (yellow cases)	Results
Heel (°) -20,00	From the Hull : From the Mass :
Height (cm) 1,5935	> Disp. (m3) 0,10201 / Disp. (m3) 0,10201
	Xc (m) 1,915 Ym (m) -0,0010
	Yc (m) 0,0782 > GZ (cm) -7,92
	Zc (m) -0,036 > RM (Kg.m) -8,08
	> Sw (m2) 1,871 FB mini (cm) 10,3

So, with the asymmetric hull, on both sides with 20° of heel angle, we still have both a clear restoring moment and a minimum of freeboard > 10 cm.

The symmetric hull, at heel 20° on starboard side :



>>> The equilibrium being at already at 16°35, at 20° the GZ is of course very small, leading to an RM of just 0,94 kg.m, **only 20% of the one for the asymmetric case**. So the available RM is low to face a disturbance on that side. The minimum freeboard is 12,1 cm.

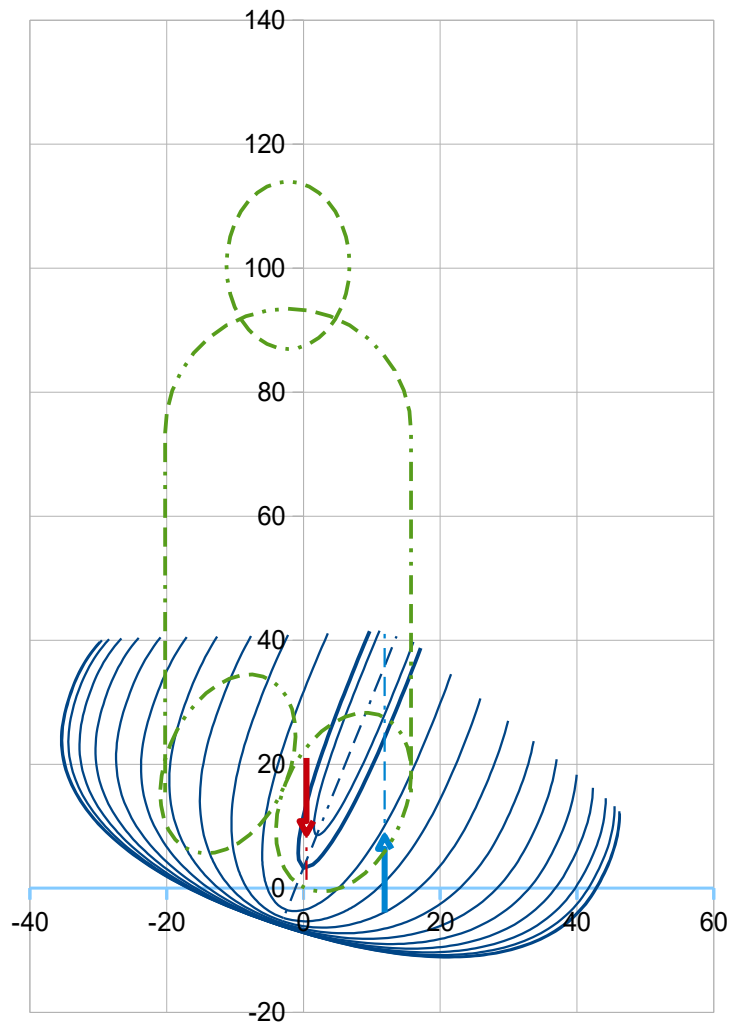
6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	(kg/m2)	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,86	22,01	2,061	0,045	0,000
Paddler (kg) >		80,00	1,900	0,20	-0,0713
Camping equipment (kg) >		0,00	0,000	0,00	0,000
M tot (kg)		102,0	1,935	0,167	-0,056
> Disp. (m3)		0,10201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacer

Data to enter (yellow cases)	Results
Heel (°) 20,00	From the Hull : From the Mass :
Height (cm) 3,4635	> Disp. (m3) 0,10201 / Disp. (m3) 0,10201
	Xc (m) 1,939 Ym (m) -0,1095
	Yc (m) -0,1188 > GZ (cm) 0,93
	Zc (m) -0,039 > RM (Kg.m) 0,94
	> Sw (m2) 1,786 FB mini (cm) 12,1

The symetric hull, at heel 20° on port side :



>>> in that case the GZ is of course great thanks to the decentering of the weight on starboard side + the symetrical sections with tumblehome. The free-board mini is 12,1 cm.

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg/m2)	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,86	22,01	2,061	0,045	0,000
Paddler (kg) >		80,00	1,900	0,20	-0,0713
Camping equipment (kg) >		0,00	0,000	0,00	0,000
M tot (kg)		102,0	1,935	0,167	-0,056
> Disp. (m3)		0,10201			

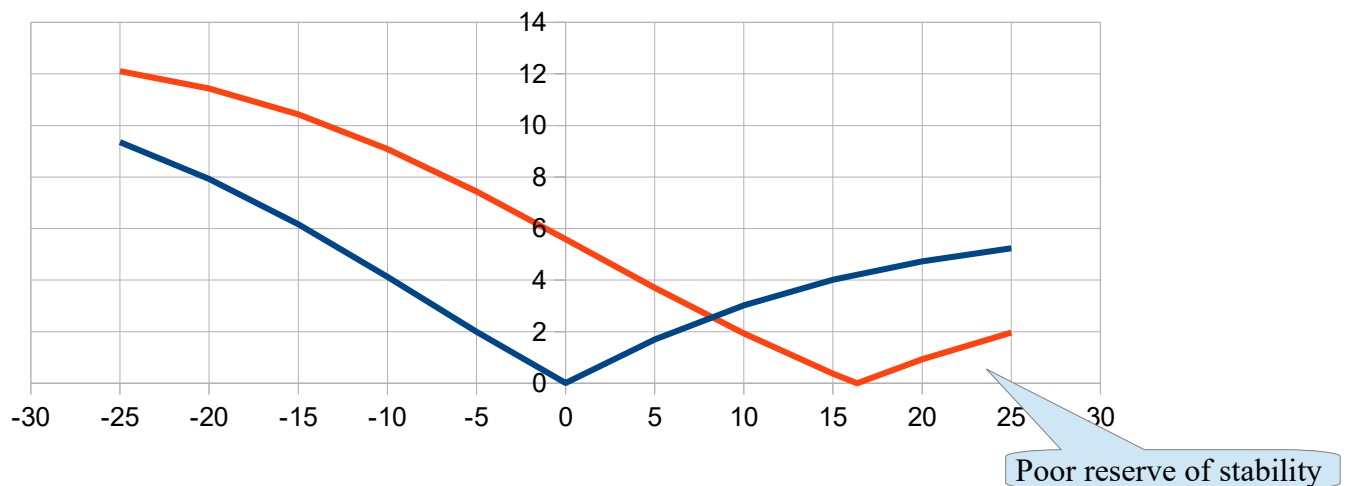
6.2 Computation : by input of Heel angle, and iteration on Height up to displacer

Data to enter (yellow cases)	Results
Heel (°) -20,00	From the Hull : > Disp. (m3) 0,10201
Height (cm) 3,4635	From the Mass : / Disp. (m3) 0,10201
	Xc (m) 1,939 Ym (m) 0,0044
	Yc (m) 0,1188 > GZ (cm) -11,43
	Zc (m) -0,039 > RM (Kg.m) -11,66
	> Sw (m2) 1,786 FB mini (cm) 12,1

GZ curve

Blue : asymetric hull ; Red ; symetric hull

Left side : heelin toward port : right side : heeling toward starboard

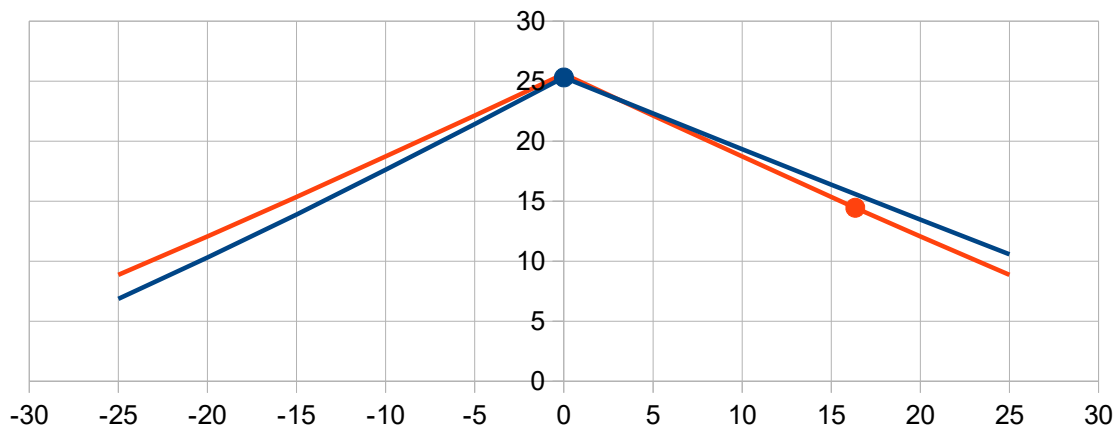


Blue curve : with the asymetric hull and a paddler decentering on the beamy side, we can recover a quasi symmetrical situation offering a similar righting moment on both sides.

Red curve : at contrary, with the symetric hull, if the paddler is decentering, the heel angle at equilibrium is already quite high (~ 16° in our example) and that left a poor reserve of stability on the wrong side. Moreover, beyond 20° and even more 25°, the paddler should no longer have the capacity to maintain his body trunk vertical. So the assumption for the body weight vector is no longer valid and the computation with this assumption should be stop there.

Minimum freeboard

Blue : with asymertric hull (blue point = at equilibrium)
Red : with symetric hull (red point = at equilibrium)



Again, with a decentering paddler, the minimum free board is lower (to less than 15 cm in our example) with the symetric hull, instead of 25 cm with the asymeric one, leaving less margin of safety.

4. Equilibrium with a paddler 80 kg decentring on starboard side and 15° of heel angle

This configuration with an asymmetric hull can be considered equivalent to the one adopted by solo paddler with a symmetric hull :

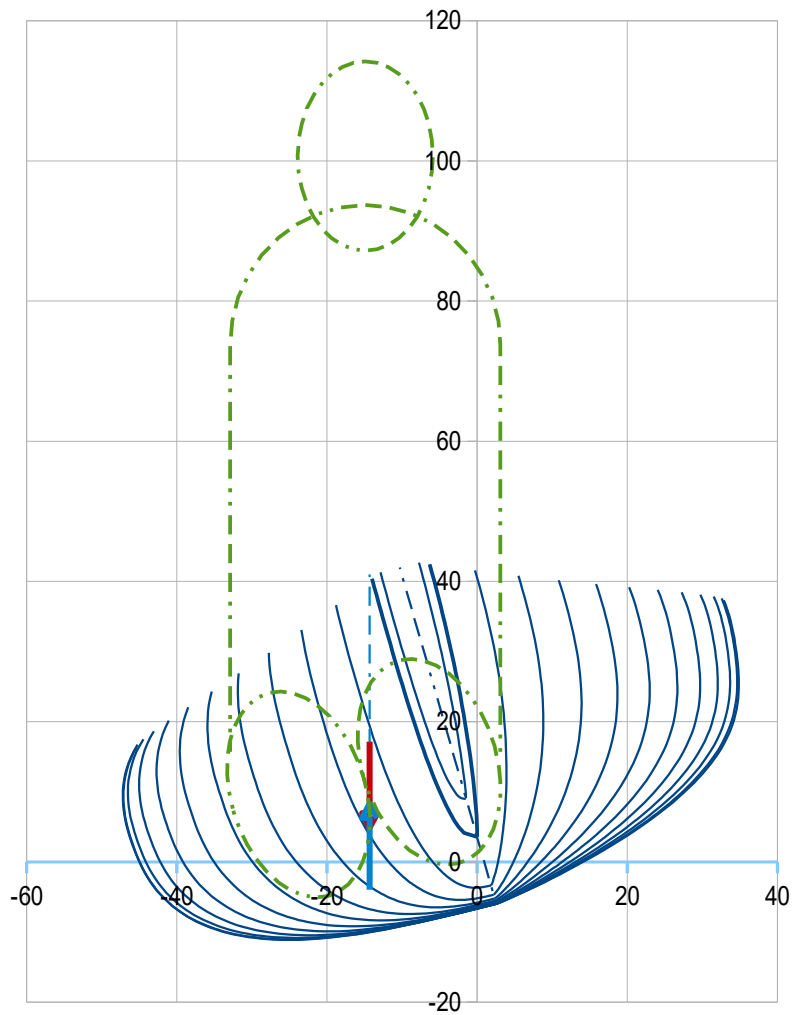
6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,85	22,01	2,060	0,047
Paddler (kg) >	80,00	1,900	0,20	-0,1240
Camping equipment (kg) >	0,00	0,000	0,00	0,000
M tot (kg)	102,0	1,934	0,167	-0,103
> Disp. (m3)	0,10201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacemer

Data to enter (yellow cases)	Results
Heel (°) 15,00	From the Hull : > Disp. (m3) 0,10201
Height (cm) 3,6920	From the Mass : / Disp. (m3) 0,10201
	Xc (m) 1,948
	Yc (m) -0,1431
	Zc (m) -0,040
	> Sw (m2) 1,744
	Ym (m) -0,1429
	> GZ (cm) 0,02
	> RM (Kg.m) 0,02
	FB mini (cm) 16,4

>>> Then, the dcentering at equilibrium is Y 12,4 cm, putting the paddler at 28 cm instead of 40 cm of the sheer line.



5. Equilibrium with a paddler 80 kg decentering on starboard side and 20 kg of equipment on port side

In that case, with the asymmetric hull, the paddler can be decentering at Y 14,6 cm for the equilibrium upright :

6.1 Simplified Mass spreadsheet (Data to enter in yellow cases)

	Mass (kg)	Xg (m)	Zg (m)	Yg (m)
Canoe (kg) >	4,85	22,01	2,060	0,047
Paddler (kg) >	80,00	1,900	0,20	-0,1460
Camping equipment (kg) >	20,00	2,000	0,10	0,250
M tot (kg)	122,0	1,945	0,156	-0,060
> Disp. (m3)	0,12201			

6.2 Computation : by input of Heel angle, and iteration on Height up to displacemer

Data to enter (yellow cases)

Heel (°)	0,00	Results		
Height (cm)	0,1740	From the Hull :	From the Mass :	
		> Disp. (m3)	/ Disp. (m3)	0,12201
		Xc (m)	Ym (m)	-0,0597
		Yc (m)	> GZ (cm)	0,01
		Zc (m)	> RM (Kg.m)	0,01
		> Sw (m2)	FB mini (cm)	24,2

