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# HOW TO DIMENSION A SAILING CATAMARAN?

This article is to help starting a catamaran design prosess. At the end of the day, the performance of a sailing catamaran is dependent on three main dimension: length, sail area and weight. More waterline length means a faster boat, more sail area means a faster boat and less weight means a faster boat.

Then there are some limits: Too much sail area capsize the boat at the breeze, too light boat will not stand in one piece, too slim hulls can not accommodate you and your friends, too long and big boat is out of financing...Then there are lot of small but important factors like underwater hull shape, aspect ratios of boards and sails, wet deck clearance, rotating or fixed rigging and so on.

The next descripton is based on basic equations and parameters of naval architecture. There are also some pick up's from ISO boat standards. In the beginnig we deside the length of the boat and the nature of her. Then we'll try to optimise other dimensions to give her a decent performance. All dimensions in the article are metric, linear dimensions are in meters (m), areas are in square meters ($m^2$), displacement volumes in cubic meters ($m^3$), masses (displacement, weight) are in kilograms (kg), forces in Newtons (N), powers in kilowatts (kW) and speeds in knots.

Catamarans are different, but they all live in the water and they all breathe the air, so these equations should fit to every catamaran from a heavy floating home to an ocean racer, from a beach cat to a performance cruiser.

**Word of warnig still: This is for premilinary design only, every dimension should check by a naval architect or by an other capable person before building a boat.**

## Hull dimensioning

### Lenght, Draft and Beam

Length, draft, beam and mass are in fully loaded condition at this stage of dimensioning. There can be found two major lengths in a boat: lengh of hull $L_H$ and length of waterline $L_{WL}$.
Let's put values here to get a calculated example.

$L_H := 12.20$ $\qquad$ $L_{WL} := 12.00$

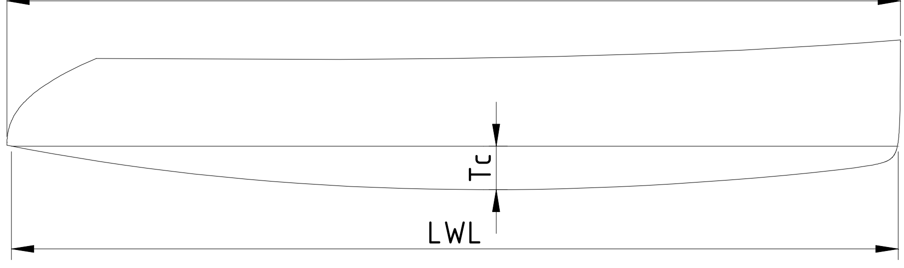


**Figure 1**

Next we make a decision of lenght/beam ratio of the hull, LBR. This is somehow overrated ratio in many depates. Simply heavy boats have low value and light racers high value. LBR well below eight leads to increased wave making and this should be avoided. Normal LBR for a cruiser is somewhere between 9 and 12. LBR has a definitive effect on boat displacement estimate.

In this example $LBR := 11.0$ and this determines beam waterline as follows:

$$B_{WL} := \frac{L_{WL}}{LBR} \qquad B_{WL} = 1.09$$

Too narrow beam waterline, well under 1 m, will cause difficulties to build accommodation in a hull.

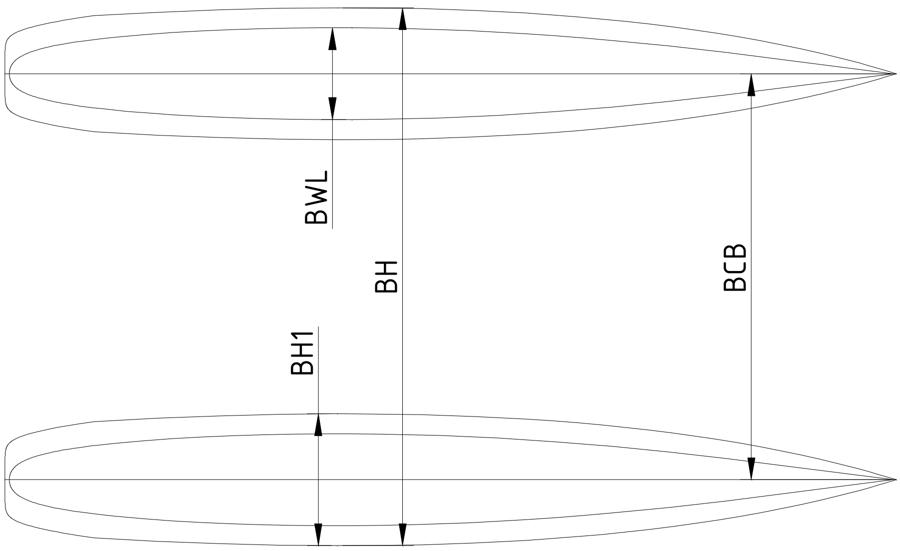


**Figure 2**

Beam/draft ratio BTR effects on the resistance of boat. Values near two minimizes friction resistance and slightly lower values minimize wave making. Reasonable values are from 1.5 to 2.8. Higher values increase load capacity. The deep-V bottomed boats have typically BTR betveen 1.1 to 1.4. BTR has also effect on boat displacement estimation.

Here we put $BTR := 1.9$ to minimize boat resistance (as her size) and get draft canoe body $T_c$ (Figure 1) as follows:

$$T_c := \frac{B_{WL}}{BTR} \qquad T_c = 0.57$$

## Coefficients

To go on we need to estimate few coefficients of the canoe body. **Midship coefficient** is defined: $C_m := \frac{A_m}{T_c \cdot B_{WL}}$ , where Am is the maximum section area of the hull (Figure 3).

$C_m$ depens on the shape of the midship section: a deep-V-section has $C_m$ = 0.5 while an ellipse section has $C_m$ = 0.785. Midship coefficient has a linear relation to displacement.

In this example we use ellipse hull shape to minimize wetted surface, so $C_m := 0.785$

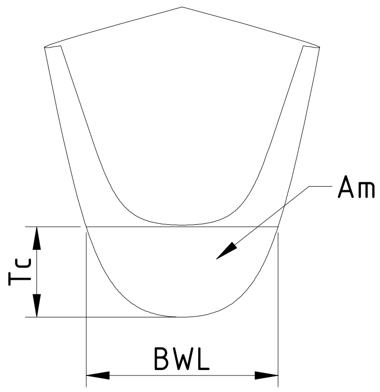


**Figure 3**

**Prismatic coefficient** is defined: $C_p := \frac{\Delta}{A_m \cdot L_{WL}}$,

where $\Delta$ is the displacement volume ($m^3$) of the boat. Prismatic coefficient has an influense on boat resistance. $C_P$ is typically between 0.55 and 0.62. Lower values (0.55-0.57) are optimized to displacement speeds and higher values to speeds over the hull speed ( $V := 2.44\sqrt{L_{WL}}$).

In this example we are seeking for a performance cat and set $C_p := 0.59$.

**Waterplane coefficient** is defined: $C_w := \frac{A_w}{B_{WL} \cdot L_{WL}}$, where Aw is waterplane (horisontal) area.

Typical value for waterplane coefficient is $C_w$ = 0.69 - 0.72. In our example $C_w := 0.71$

## Loaded displacement

At last we can do our displacement estimation. In the next formula, 2 is for two hulls and 1025 is the density of seawater (kg/$m^3$). Loaded displacement mass in kg's is:

$$m_{LDC} := 2 \cdot B_{WL} \cdot L_{WL} \cdot T_c \cdot C_p \cdot C_m \cdot 1025 \qquad m_{LDC} = 7136$$

Length/displacement -ratio, LDR, is a tool to evaluate our displacement value.

$$LDR := L_{WL} \cdot \sqrt[3]{\frac{1025}{m_{LDC}}} \qquad LDR = 6.3$$

If LDR is near four, the catamaran should be connected to a communal water- and drainsystem. Near five, the catamaran is a heavy one and made from solid laminate. Near six, the catamaran has a modern sandwich construction. In a performance cruiser LDR is usually between 6.0 and 7.0. Higher values than seven are reserved to big racers and super high tech beasts.
Use 6.0 as a target for LDR in a glass-sandwich built cruising catamaran.

To adjust LDR and fully loaded displacement $m_{LDC}$, change the length/beam ratio of hull, LBR.

We can now estimate our empty boat displacement (kg):

$$m_{LCC} := 0.7 \cdot m_{LDC} \qquad m_{LCC} = 4995$$

This value must be checked after weight calculation or prototype building of the boat.

The light loaded displacement mass (kg), this is the mass we will use in stability and performance prediction:

$$m_{MOC} := 0.8 \cdot m_{LDC} \qquad m_{MOC} = 5709$$

## Beam of catamaran

The beam of a sailing catamaran is a fundamental thing. Make it too narrow, and she can't carry sails enough to be a decent sailboat. Make it too wide and you end up pich-poling with too much sails on. The commonly accepted way is to design longitudinal and transversal metacentric heights equal. Here we use the height from buoyancy to metacenter.

The beam between hull centers is named $B_{CB}$ (Figure 2). Length/beam ratio of the catamaran, LBRC*,* is defined as follows: length of hull $L_H$ divided by beam between hull centers $B_{CB}$.

If we set $LBRC := 2.2$, the longitudinal and transversal stability will come very near to the same value. You can design a sailing catamaran wider or narrower, if you like. Wider construction makes her heavier, narrower makes her carry less sails.

So we can calculate the beam between hull centers (m):

$$B_{CB} := \frac{L_H}{LBRC} \qquad B_{CB} = 5.55 \qquad \text{(Figure 2)}$$

Transversal stability (height from bouyancy to metacenter) can be estimated as follows. The formula is somehow approximated but precise enough for the purpose:

$$BM_T := 2\cdot\left[\frac{B_{WL}{}^3\cdot L_{WL}\cdot C_w{}^2}{12} + L_{WL}\cdot B_{WL}\cdot C_w\cdot\left(0.5B_{CB}\right)^2\right]\cdot\frac{1025}{m_{LDC}} \qquad BM_T = 20.7$$

Then longitudinal stability can be estimated as follows. The formula is more empirical but again precise enough for the purpose:

$$BM_L := \frac{2\cdot 0.92\cdot L_{WL}{}^3\cdot B_{WL}\cdot C_w{}^2}{12}\cdot\frac{1025}{m_{LDC}} \qquad BM_L = 20.9$$

Too low value of $BM_L$ (well under 10) will make her sensitive to hobby-horsing.

We still need to determine the beam of one hull $B_{H1}$ (Figure 2). If the hulls are asymmetric above waterline this is a sum of outer hull halves. $B_{H1}$ must be bigger than $B_{WL}$ of the hull.
We'll put here in our exaple $B_{H1} := 1.4\cdot B_{WL}$
Now we can calculate the beam of our catamaran, simply:

$$B_H := B_{H1} + B_{CB} \qquad B_H = 7.07 \qquad \text{(Figure 2)}$$

## Wet deck clearance

Minimum wet deck clearance at fully loaded condition is defined here to be 6 % of $L_{WL}$:

$$Z_{WD} := 0.06\cdot L_{WL} \qquad Z_{WD} = 0.72$$

## EU Size factor

The size factor of the catamaran is defined as follows:

$$SF := 1.75 \cdot m_{MOC} \cdot \sqrt{L_H \cdot B_{CB}} \qquad SF = 82 \times 10^3$$

While the length/beam ratio of catamaran, LBR, is between 2.2 and 3.2, the value of size factor above 40000 justifies to A-catagory and above 15000 to B-category.

# Rig dimensioning

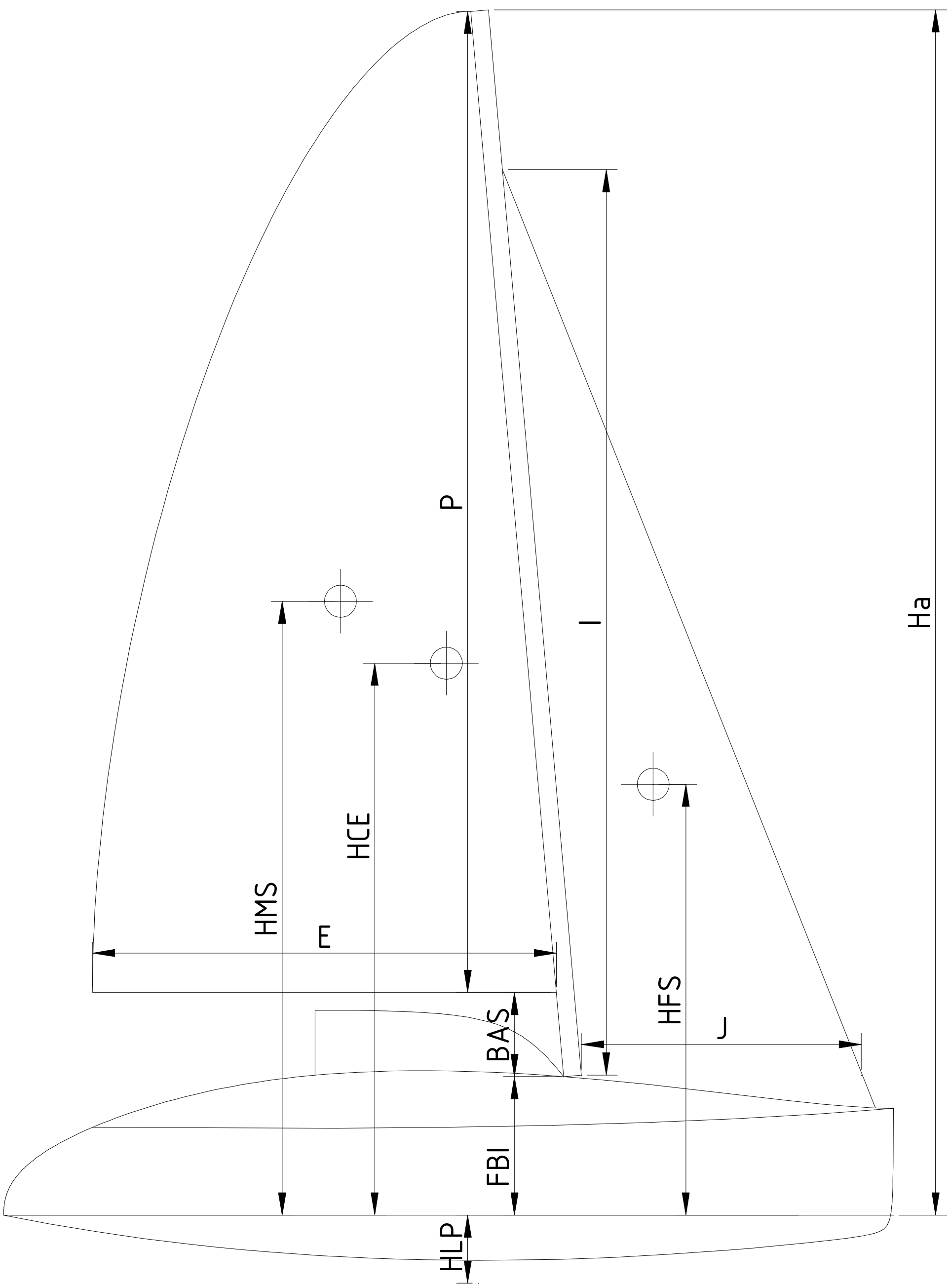


**Figure 4**

## Rig ratios

A handy way to do the rig dimensioning is is to use proportional ratios for dimensions. Rig dimensions are then in relation to length waterline $L_{WL}$. For example:

Mainsail luff ratio: $k_P := 125\%$

Mainsail base ratio: $k_E := 52\%$

Foretriangle base ratio: $k_J := 33\%$

Jib area ratio: $k_F := 140\%$ (while a 100% is the foretriangle area)

Foresails: self tacking jib 90%, jib 110-120%, genoa 130-150%

Other dimensions are from the catamaran structure:

Freeboard at mast $F_{BI} := 1.63$

Mainsail above mast foot $B_{AS} := 1.1$

Calculated values for our rig are then:

## Rig dimensions

| | | |
|---|---|---|
| $P := k_P \cdot L_{WL}$ | $P = 15.00$ | Mainsail luff (m) |
| $E := k_E \cdot L_{WL}$ | $E = 6.24$ | Mainsail base (m) |
| $I := 0.85 \cdot (P + B_{AS})$ | $I = 13.69$ | Forertiangle height (m) |
| $J := k_J \cdot L_{WL}$ | $J = 3.96$ | Foretriangle base (m) |
| $\Lambda_M := \frac{P}{E}$ | $\Lambda_M = 2.40$ | Mainsail aspect ratio |
| $\Lambda_F := \frac{I}{J}$ | $\Lambda_F = 3.46$ | Foretriangle aspect ratio |
| $A_{MS} := 0.7 \cdot P \cdot E$ | $A_{MS} = 65.5$ | Mainsail area ($m^2$) |
| $A_{FS} := 0.5 \cdot I \cdot J \cdot k_F$ | $A_{FS} = 37.9$ | Foresail area ($m^2$) |
| $A_S := A_{MS} + A_{FS}$ | $A_S = 103.5$ | Sail area upwind ($m^2$) |
| $A_G := 1.65 \cdot I \cdot J$ | $A_G = 89.4$ | Gennaker area ($m^2$) |
| $H_a := P + B_{AS} + F_{BI}$ | $H_a = 17.73$ | Air draft (m) |
| $H_{LP} := 0.04 \cdot \sqrt[3]{m_{LDC}}$ | $H_{LP} = 0.77$ | Depth of lateral area (m) |
| $H_{MS} := F_{BI} + B_{AS} + 0.4 \cdot P$ | $H_{MS} = 8.73$ | Height of mainsail center (m) |
| $H_{FS} := F_{BI} + 0.4 \cdot I$ | $H_{FS} = 7.10$ | Height of foresail center (m) |
| $H_{CE} := \frac{A_{MS} \cdot H_{MS} + A_{FS} \cdot H_{FS}}{A_S}$ | $H_{CE} = 8.13$ | Height of centre of effort (m) |

## Stability on sailing

The most important thing for the catamaran is to carry the sails in the design conditions. This is why we have to sort out how much wind is needed to lift the windward hull out of the water. This wind is called design wind speed $V_{WAK}$.
We also want to know the windspeed we need to take the first reef. This wind is called reefing wind speed $V_W$ . Both of these are apparent wind speeds. Stability on sailing is calculated in light loaded condition, $m_{MOC}$.

First we calculate the heel angle she touch the water. This software uses radians for angles.

$$\Phi_{GZmax} := atan\left(\frac{m_{MOC}}{254 \cdot L_{WL} \cdot 2B_{WL} \cdot B_{CB}}\right)$$

$\Phi_{GZmax} = 0.154$ Heel angle in radians

$\Phi_{GZmax} \cdot \frac{180}{\pi} = 8.8$ Heel angle in degrees

Maximum transversal righting moment in Nm is defined as:

$$LM_R := 9.4 \cdot m_{MOC} \cdot \left(0.5B_{CB} \cdot cos\left(\Phi_{GZmax}\right) - F_{BI} \cdot sin\left(\Phi_{GZmax}\right)\right) \qquad LM_R = 133.7 \times 10^3$$

For the longitudinal righting moment we need the waterplane area of the boat:

$$A_{WP} := 2 \cdot C_w \cdot L_{WL} \cdot B_{WL} \qquad A_{WP} = 18.6$$

Maximum longitudinal righting moment in Nm is defined as:

$$LM_P := 2.45 \cdot m_{MOC} \cdot \frac{A_{WP}}{2B_{WL}} \qquad LM_P = 119.2 \times 10^3$$

The limiting righting moment we will use for our catamaran stability is in Nm:

$$LM := if\left[\frac{\left(L_H + L_{WL}\right)}{B_{CB}} \geq 4, LM_R, min\left(LM_R, LM_P\right)\right] \qquad LM = 133.7 \times 10^3$$

Design wind speed in knots is defined as follows:

$$V_{AWK} := \sqrt{\frac{LM}{0.16 \cdot A_S \cdot \left(H_{CE} + H_{LP}\right)}} \qquad V_{AWK} = 30.1$$

Reefing wind speed in knots is defined as:

$$V_W := 1.6\sqrt{\frac{LM}{A_S \cdot \left(H_{CE} + H_{LP}\right)}} \qquad V_W = 19.3$$

If the reefing wind speed is unnecessary high, simpy increase the mainsail luff ratio $k_P$ , and if reefing wind speed is too low we need to decrease mainsail luff ratio.

## Appendages

First we calculate the nominal sail area and centre of effort. These values are independent on the foresail size.

$A_N := 0.7\cdot(P\cdot E) + 0.5(I\cdot J)$ $A_N = 92.6$ Nominal sail area ($m^2$)

$H_{CEN} := \dfrac{A_{MS}\cdot H_{MS} + 0.5I\cdot J\cdot H_{FS}}{A_N}$ $H_{CEN} = 8.25$ Height of centre of effort (m)

The maximum side force in N for our catamaran is:

$F_S := \dfrac{LM}{H_{CEN} + H_{LP}}$ $F_S = 14.8\times 10^3$ Max side force (N)

The maximum boat speed using nominal sail area in fully loaded condition is in m/s:

$V_{uw} := \dfrac{1.64\cdot V_W^{0.66}\cdot L_{WL}^{0.3}\cdot A_N^{0.4}}{m_{LDC}^{0.3}}\cdot\dfrac{1852}{3600}$ $V_{uw} = 5.4$

The equation above is modified from Texel rating system.

How much of side force is taken by the hulls? We take leeway angle in degrees of: $\alpha_L := 5.0$

$C_{LH} := \dfrac{0.1\cdot\alpha_L}{\left(1 + \dfrac{2L_{WL}}{T_c}\right)}$ $C_{LH} = 0.012$ Lift coefficient of the hull

$C_{pl} := \dfrac{C_p\cdot C_m}{C_w}$ $C_{pl} = 0.65$ Prismatic coefficient longitudinal

$A_{LP} := C_{pl}\cdot T_c\cdot L_{WL}$ $A_{LP} = 4.5$ Lateral area of hull ($m^2$)

Lateral force of the hulls can then be calculated as follows:

$F_H := 2\cdot C_{LH}\cdot 0.5\cdot 1025\cdot A_{LP}\cdot V_{uw}^2$ $F_H = 1.54\times 10^3$ Lateral force of hulls (N)

The rest of the side force must be handled by the boards. First we deside the geometric aspect ratio of our boards: $\Lambda_A := 2.5$

$F_{SB} := 0.5\cdot\left(F_S - F_H\right)$ $F_{SB} = 6.63\times 10^3$ Side force of one board (N)

$C_L := \dfrac{0.1\cdot\alpha_L}{1 + \dfrac{2}{\Lambda_A}}$ $C_L = 0.278$ Lift coefficient of boards

So we can solve the area of the boards in one hull:

$A_B := \frac{F_{SB}}{C_L \cdot 0.5 \cdot 1025 \cdot V_{uw}^2}$ $A_B = 1.63$ Area of board needed ($m^2$)

## Daggerboard

The daggerboard area is preset to 70% of the board area:

$A_d := 0.7 \cdot A_B$ $A_d = 1.14$ Area of daggerboard ($m^2$)

$T_d := \sqrt{A_A \cdot A_d}$ $T_d = 1.69$ Draft of daggerboard (m)

$C_d := \frac{A_d}{T_d}$ $C_d = 0.67$ Chord of daggerboard (m)

## Rudderboard

And the rest of the board area is a rudder:

$A_r := 0.3 \cdot A_B$ $A_r = 0.49$ Area of rudderboard ($m^2$)

$T_r := \sqrt{A_A \cdot A_r}$ $T_r = 1.10$ Draft of rudderboard (m)

$C_r := \frac{A_r}{T_r}$ $C_r = 0.44$ Chord of rudderboard (m)

# Powering

The engine power needed for the catamaran is typically 4 kW/tonne and the motoring speed is the hull speed, so:

$P_m := 4 \cdot \frac{m_{LDC}}{1025}$ $P_m = 28$ Engine Power (kW)

$V_m := 2.44 \cdot \sqrt{L_{WL}}$ $V_m = 8.5$ Motoring speed (knots)

# Performance

This is a purely empirical formula for the wetted surface area:

$$A_{WS} := \frac{\sqrt{B_{WL}^2 + (2T_c)^2}}{B_{WL}} \cdot \left(1.2434 \cdot C_m^3 - 1.4545 \cdot C_m^2 + 0.6935 \cdot C_m + 0.8614\right) \cdot A_{WP} \qquad A_{WS} = 30.0$$

Sail area/wetted surface ratio is calculated as follows (note the boards are included):

$$SWR := \frac{A_S}{A_{WS} + 4A_B} \qquad SWR = 2.8$$

Sail area/wetted surface ratio

Sail area/wetted surface ratio should be more than 2.5 to show a fast boat in light wind.

The next one is commonly used sail area/displacement ratio:

$$SDR := \frac{A_S}{\left(\frac{m_{LDC}}{1025}\right)^{0.667}} \qquad SDR = 28.4$$

Sail area/displacement ratio

## Boatspeed

These boatspeed formulas are modified from Texel rating to show the speed potential of our catamaran at the reefing wind speed. The boat is in light loaded condition (racing).

The first result is the average boatspeed potential with jib or genoa (in knots):

$$V_{uw1} := \frac{1.64 \cdot V_W^{0.66} \cdot L_{WL}^{0.3} \cdot A_S^{0.4}}{m_{MOC}^{0.3}} \qquad V_{uw1} = 11.6$$

The second is the average speed potential with gennaker (in knots):

$$V_{uw2} := \frac{1.64 \cdot V_W^{0.66} \cdot L_{WL}^{0.3} \cdot \left(A_{MS} + A_G\right)^{0.4}}{m_{MOC}^{0.3}} \qquad V_{uw2} = 13.7$$

# Cost guestimation

Euros are material cost of catamaran and hours are work of one off boat.

$$Euros := 3 \cdot m_{LCC} \cdot LDR \qquad Euros = 94.2 \times 10^3$$

$$Hours := \frac{LDR}{5} \cdot m_{LCC} \qquad Hours = 6.3 \times 10^3$$