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HOW TO DIMENSION A SAILING CATAMARAN?

This article is to help start a catamaran design process. At the end of the day, the performance of a sailing catamaran is dependent on three main dimensions: 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 capsizes the boat in the breeze, a too light boat will not stand in one piece; too slim hulls can not accommodate you and your friends; too long and big a 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 description is based on basic equations and parameters of naval architecture. There are also some pick ups from ISO boat standards. In the beginning we decide the length of the boat and the nature of her. Then we'll try to optimize 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 Newton's (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.

A word of warning still: This is for preliminary design only, every dimension should be checked by a naval architect, or by an other capable person before building a boat.

Hull dimensioning

Length, 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: length of hull L_H and length of waterline L_{WL}.
Let's put in some values to get a calculated example.

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

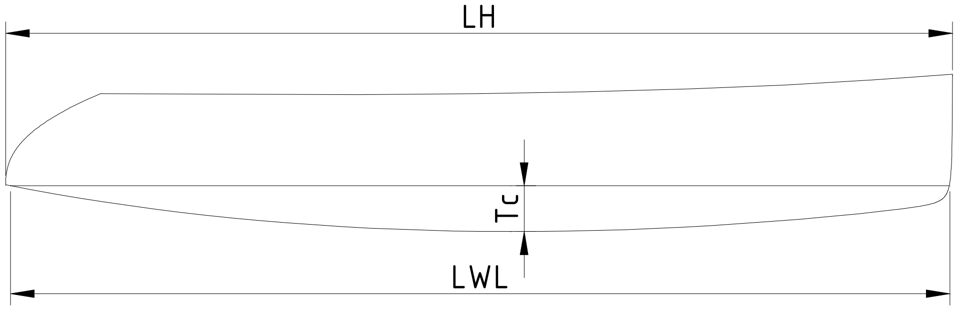

Figure 1

Next we make a decision of length/beam ratio of the hull, LBR. This is somehow over rated ratio in many debates. 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. Lower values increase loading capacity. 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 beam waterline B_{WL} will be:

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

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

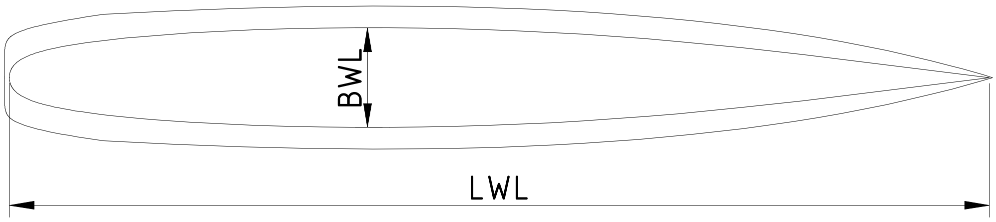

Figure 2

Beam/draft ratio BTR effects on the resistance of boat. $BTR := \frac{B_{WL}}{T_c}$

A value 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 between 1.1 and 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 a 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 depends 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 $C_m := 0.785$

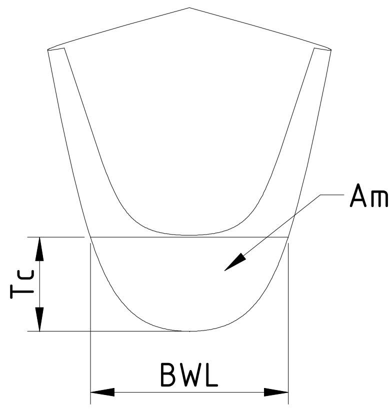

Figure 3

Prismatic coefficient is defined $C_p := \frac{\Delta}{A_m \cdot L_{WL}}$, where Δ is the displacement volume (m^3) of the boat. Prismatic coefficient has an influence on boat resistance. C_P is typically between 0.55 and 0.64. Lower values (< 0.57) are optimized to displacement speeds, and higher values (> 0.60) to speeds over the hull speed (hull speed $V := 2.44\sqrt{L_{WL}}$).

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

Water plane coefficient is defined: $C_w := \frac{A_w}{B_{WL} \cdot L_{WL}}$, where Aw is water plane (horizontal) area.

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

Fully 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 sea water (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 loaded displacement value.

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

LDR 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 for big racers and super high tech beasts.

Use 6.0 to 6.5 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 sailing 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 pitch-poling with too much sails on. The commonly accepted way is to design longitudinal and transversal metacenter heights equal. Here we use the height from buoyancy to metacenter (commonly named BM).

The beam between hull centers is named B_{CB} (Figure 2). Length/beam ratio of the catamaran, LBRC*,* is defined as follows: $LBRC := \frac{L_H}{B_{CB}}$. 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 sail. So we can calculate the beam between hull centers (m):

$$B_{CB} := \frac{L_H}{LBRC} \qquad B_{CB} = 5.55$$

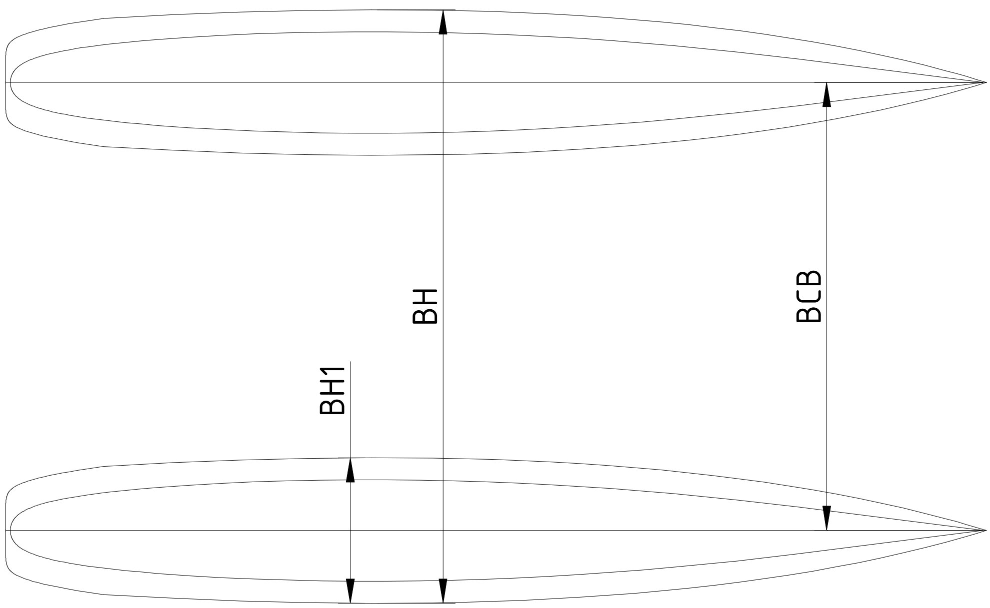

Figure 4

Transversal height from the center of buoyancy to metacenter, BM_T can be estimated as follows:

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

Longitudinal height from the center of buoyancy to metacenter, BM_L can be estimated as follows:

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

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 4). 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 example: $B_{H1} := 1.4 \cdot B_{WL}$

Now we can calculate the beam of our catamaran B_H (Figure 4):

$B_H := B_{H1} + B_{CB}$ $\qquad B_H = 7.07$

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, LBRC, is between 2.2 and 3.2, a catamaran can be certified to A category if SF > 40 000 and to B category if SF > 15 000.

Powering

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

$P_m := 4 \cdot \frac{m_{LDC}}{1025}$ $\qquad P_m = 28$ $\qquad$ Installed power total (kW)

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

Wanted motoring range in nautical miles $R_m := 300$

A diesel engine consume on half throttle approximately: $con := 0.15$kg/kWh.
The fuel tank of diesel with 20% of reserve is then:

$Vol := 1.2 \cdot \frac{R_m}{V_m} \cdot con \cdot P_m$ $\qquad Vol = 178$

Sails

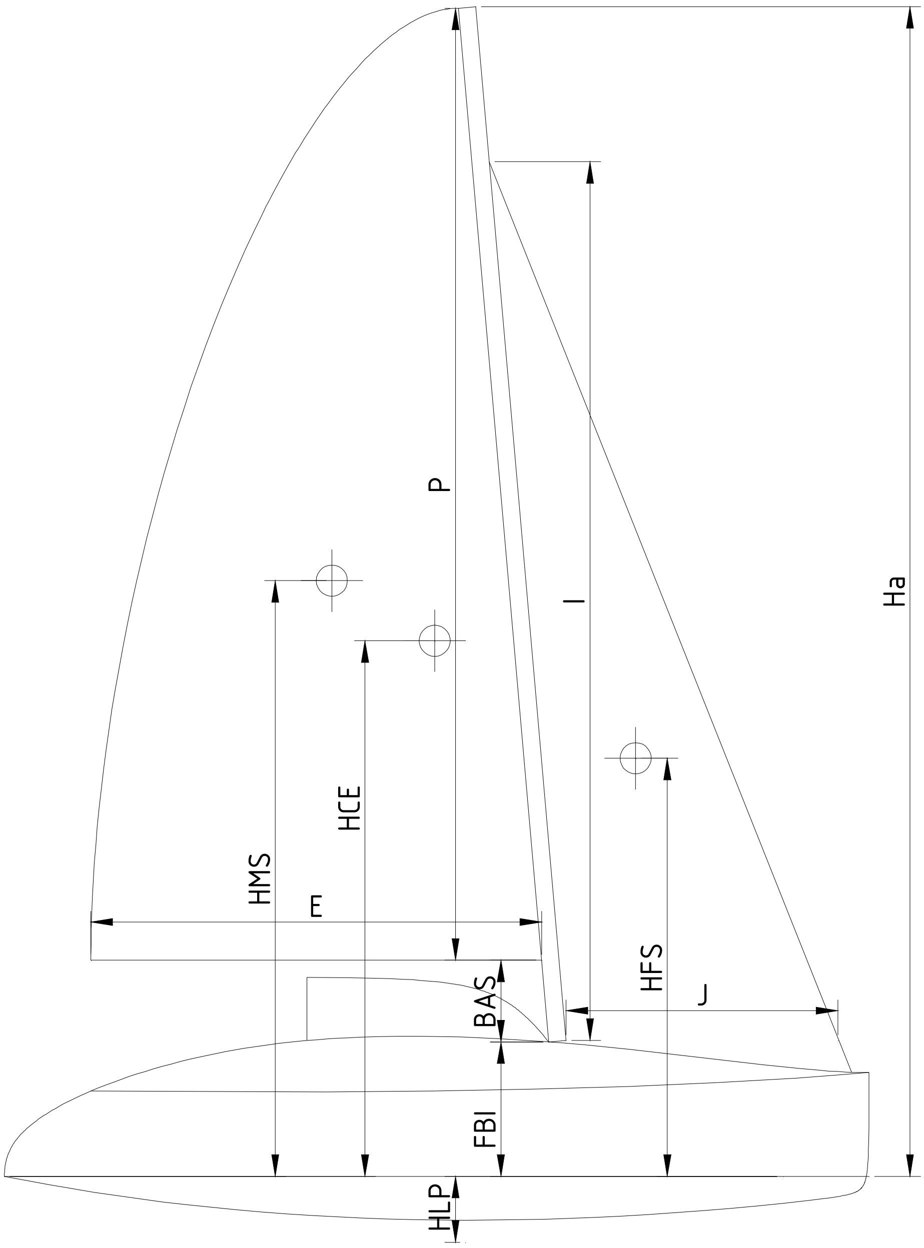

Figure 5

Sail ratios

A handy way to do the sail dimensioning is to use proportional ratios for dimensions. Sail dimensions are then in relation to length waterline L_{WL} = 100%. For example:

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

Mainsail base E ratio: $k_E := 50\%$

Fore triangle base J ratio $k_J := 36\%$

Other dimensions are from the catamaran structure:

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

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

Sail dimensions

$P := k_P \cdot L_{WL}$	$P = 15.00$	Mainsail luff (m)
$E := k_E \cdot L_{WL}$	$E = 6.00$	Mainsail base (m)
$I := 0.85 \cdot (P + B_{AS})$	$I = 13.69$	Fore triangle height (m)
$J := k_J \cdot L_{WL}$	$J = 4.32$	Fore triangle base (m)
$\Lambda_M := \frac{P}{E}$	$\Lambda_M = 2.50$	Mainsail aspect ratio
$\Lambda_F := \frac{I}{J}$	$\Lambda_F = 3.17$	Fore triangle aspect ratio, change the value of k_J, to get Λ_F between 2.8 and 3.5 (better 3.0 - 3.2)
$A_{MS} := 0.7 \cdot P \cdot E$	$A_{MS} = 63.0$	Mainsail area (m^2), 0.7 has chosen for high roach, 0.5 is a standard
$A_{FT} := 0.5 \cdot I \cdot J$	$A_{FT} = 29.6$	Fore triangle area (m^2)
$A_S := A_{MS} + A_{FT}$	$A_S = 92.6$	Sail area (m^2)
$A_G := 1.65 \cdot I \cdot J$	$A_G = 97.5$	Gennaker area (m^2)
$H_a := 1.01 \cdot P + B_{AS} + F_{BI}$	$H_a = 17.88$	Air draft (m)
$H_{LP} := 0.04 \cdot \sqrt[3]{m_{LDC}}$	$H_{LP} = 0.77$	Height of underwater lateral center (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 fore triangle center (m)
$H_{CE} := \frac{A_{MS} \cdot H_{MS} + A_{FT} \cdot H_{FS}}{A_S}$	$H_{CE} = 8.21$	Height of center of effort (m)

Righting / heeling moment (ISO 12215-9)

Righting moment

The most important thing for the catamaran is to carry the sails in the design conditions.
The righting moment of catamaran (Nm) caused by the boat size is:

$$RM_D := 10 \cdot m_{LDC} \cdot \frac{B_{CB}}{2} \qquad RM_D = 197.9 \times 10^3$$

Heeling moment

The design wind speed of cruising catamaran is typically $V_{AWK} := 32$ knots. With the big catamarans, L_{WL} > 18 m, the design wind speed can be lower. Also in category B, the design wind speed is lower, 25 knots. The heeling moment caused by the design wind speed is:

$$HM_D := 0.16 \cdot A_S \cdot V_{AWK}^2 \cdot (H_{CE} + H_{LP}) \qquad HM_D = 136.2 \times 10^3$$

Design moment of mast

On small catamarans the righting moment RM_D is bigger than the heeling moment HM_D and then the design moment is the righting moment. On bigger catamarans the opposite is true and so their design moment is the heeling moment. In general the smaller moment will be chosen.

$$M_D := min(RM_D, HM_D) \qquad M_D = 136.2 \times 10^3$$

Racing catamarans will fly their windward hull, which is why their design moment must always be the righting moment.

Stability on sailing (ISO 12217-2)

For the safety sake a sailor need to know when it is the time to reef. In a catamaran this is indicated with the reefing wind speed V_W (apparent wind).
At first we estimate the heel angle of maximum righting arm:

$$\Phi_{GZmax} := atan\left(\frac{m_{MOC}}{254 \cdot L_{WL} \cdot 2B_{WL} \cdot B_{CB}}\right) \qquad \Phi_{GZmax} \cdot \frac{180}{\pi} = 8.8$$

Heel angle

Limiting moment in roll (Nm) for a catamaran is:

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

For the limiting moment in pitch we need the water plane area (m^2) of the boat:

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

Limiting moment in pitch (Nm) for a catamaran is:

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

The limiting moment to be used for our catamaran is:

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

Reefing wind speed (apparent wind) in knots is:

$$V_W := 1.6\sqrt{\frac{LM}{A_S \cdot (H_{CE} + H_{LP})}} \qquad V_W = 20.3$$

If the reefing wind speed is unnecessarily high, simply increase the mainsail luff ratio k_P , and if reefing wind speed is too low, decrease the mainsail luff ratio.

Appendages

The hulls and boards need to create lift enough to have acceptable leeway. First we'll estimate the maximum side force in N of the catamaran:

$$F_S := \frac{LM_R}{H_{CE} + H_{LP}} \qquad F_S = 14.9 \times 10^3$$

The maximum boat speed in m/s, using nominal sail area in fully loaded condition is calculated by simplified Texel rating system as follows:

$$V_{uw} := \frac{1.64 \cdot V_W^{0.66} \cdot L_{WL}^{0.3} \cdot A_S^{0.4}}{m_{LDC}^{0.3}} \cdot \frac{1852}{3600} \qquad V_{uw} = 5.5$$

Next we'll estimate how much side force is taken by the hulls. Leeway angle is set $\alpha_L := 5.0$

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

$$C_{pl} := \frac{C_p \cdot C_m}{C_w} \qquad C_{pl} = 0.65$$ Longitudinal prismatic coefficient of the hull

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

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

$$F_H := 2 \cdot C_{LH} \cdot 0.5 \cdot 1025 \cdot A_{LP} \cdot V_{uw}^2 \qquad F_H = 1.65 \times 10^3$$

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

$$F_{SB} := 0.5 \cdot (F_S - F_H) \qquad F_{SB} = 6.62 \times 10^3$$ Side force of one board (N)

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

At last we can solve the area of the boards in one hull:

$$A_B := \frac{F_{SB}}{C_L \cdot 0.5 \cdot 1025 \cdot V_{uw}^{\,2}} \qquad A_B = 1.52$$

Centerboard

The centerboard area is preset to 75% of the board area:

$A_d := 0.75 \cdot A_B$	$A_d = 1.14$	Area of centerboard (m²)
$T_d := \sqrt{A_A \cdot A_d}$	$T_d = 1.69$	Draft of centerboard (m)
$C_d := \frac{A_d}{T_d}$	$C_d = 0.67$	Chord of centerboard (m)

Rudder

And the rest of the board area is a rudder:

$A_r := 0.25 \cdot A_B$	$A_r = 0.38$	Area of rudder (m²)
$T_r := \sqrt{A_A \cdot A_r}$	$T_r = 0.97$	Draft of rudder (m)
$C_r := \frac{A_r}{T_r}$	$C_r = 0.39$	Chord of rudder (m)

Performance

Wetted surface of catamaran can be estimated as follows:

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

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

$$SWR := \frac{A_S}{A_{WS} + 4A_B} \qquad SWR = 2.6$$

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:

$$SDR := \frac{A_S}{\left(\frac{m_{LDC}}{1025}\right)^{0.667}} \qquad SDR = 25.4$$

SDR > 20 in general means good performance

Bruce number in imperial units:

$$BN := \frac{\sqrt{10.764 \cdot A_S}}{\sqrt[3]{2.2046 \cdot m_{LDC}}} \qquad BN = 1.26$$

Boat speed

These boat speed formulas are modified from Texel rating to show the speed potential of catamaran at the reefing wind speed. The boat is in light loaded condition m_{MOC}.

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

$$V_{uw1} := \frac{1.64 \cdot V_W^{0.66} \cdot L_{WL}^{0.3} \cdot A_S^{0.4}}{m_{MOC}^{0.3}} \qquad V_{uw1} = 11.5$$

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

$$V_{uw2} := \frac{1.64 \cdot V_W^{0.66} \cdot L_{WL}^{0.3} \cdot \left(A_{MS} + A_G\right)^{0.4}}{m_{MOC}^{0.3}} \qquad V_{uw2} = 14.3$$

Cost estimation

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

$$Euros := 4 \cdot LDR \cdot m_{LCC} \qquad Euros = 125.6 \times 10^3$$

$$Hours := \frac{LDR}{6} \cdot m_{LCC} \qquad Hours = 5.2 \times 10^3$$

LDR is included in estimation, because building a lighter boat needs more time and the materials are more expensive. In general the building time and cost are proportional to the mass of the boat m_{LCC}.