SAIL AREA RATIOS

Below are a few sail area calculations to consider. Naturally, opinion varies re: what is adequate sail area. These ratios therefore merely yield an approximate range. They are an attempt to take empirical feedback from sailmakers, boat owners, racers, cruisers, designers, and come up with a rule of thumb.

No 'absolute' rules can be applied since each boat will have a different ability to carry sail, and a different performance requirement. That said, here are the ratios:

The most commonly applied ratio is Sail Area to Displacement:

$$\frac{\text{Square Feet of Sail Area}}{\sqrt[3]{\text{Cubic Feet of Displacement}^2}} = 15 \text{ to } 17$$

Below 15 a slow boat will likely be the result. If a boat can stand up to it, I use 17 as a starting point for working sail, then add drifters, tops'ls, etc. Here, though, I'm working with cruising types of boats.

For a "performance cruiser" that can definitely stand up to it, a ratio as high as 20 might be right. For a racing boat it may not be uncommon to find a ratio of 22, maybe even more. Most of the performance oriented boats will be relying on light sails to make up the total, so you may find that drifters, etc. need to be included to permit the higher ratios.

My own preliminary formula is parallel to the above:

$$\text{Minimum Sail Area for Cruisers} \geq 5 \sqrt{\text{Pounds Displacement}}$$

The displacement ratios above express what is appropriate to drive the boat at speed. For drifting conditions, before wave making resistance becomes significant, the wetted surface is much more of a factor. So, the Sail Area to Wetted Surface is figured:

$$\frac{\text{Sq. Ft. Sail Area}}{\text{Sq. Ft. Wetted Surface}} = \pm\ 2.2 \text{ to } 2.4$$

With a 'working sail area' below a ratio of 2, the boat will need plenty of light sails. A boat with a ratio above 2.6 should be excellent in light airs.

Tom Colvin offers the following:

$$WL\ Length \bullet WL\ Beam \bullet 2.75 = Approx.\ Sail\ Area$$

$$WP\ Area \bullet 3.75 = Approx.\ Sail\ Area$$

$$\frac{\sqrt[2]{Sq.\ Ft.\ Sail\ Area}}{\sqrt[3]{Cubic\ Feet\ Displacement}} = 3.8 \text{ to } 4.0$$

Colvin also says there should be around 4 to 6 sq. ft. of Sail Area per sq. ft. of Lateral Plane Area. In other words, Lateral Plane should equal around 16% to 25% of the Sail Area.

It should be noted that Lateral Plane is not ordinarily used to determine Sail Area. Instead it is the opposite: Sail Area is used to determine the amount of Lateral Plane.

For a full keel boat, Kinney says Lateral Plane should equal about 12% to 16% of the sail area. While this is much lower than Colvin's recommendation, it refers to profiles that are more cut-away at the ends. Per Kinney, a fin keel boat, should have an LP around 7% to 10% of the Sail Area. The Lateral Plane ordinarily includes half the rudder.

The above Sail Area targets are for "medium" sized boats. Smaller boats being less stable inherently cannot use as much sail area. Larger boats being more stable can often take advantage of higher ratios.

These ratios use actual true areas of the individual sails are considered, i.e. the 'working' sail area rather than the area calculated by various racing rule measurements. For example in calculating the above the "fore triangle area" is not an important number.

SAIL AREA vs STABILITY

All of the above ratios are preliminary approximations. The real test is whether the boat can stand up to the amount of sail proposed.

Initial stability, or the power to carry sail, is related to a boat's roll period. A boat that rolls quickly is more stiff. A boat that rolls slowly is more tender. The range of typical roll periods for sailing yachts given in Skene's by Kinney is between 4 seconds and 8 seconds. This will vary with the size of boat. Smaller boats will roll more quickly, even if more tender.

In The Design of Sailing Yachts (page 157) Pierre Gutelle gives an interesting graph to provide an approximate sail area target based on a boat's "Stability Index." Units are meters and kilograms.

Wind Pressure Coefficient

Kinney gives two methods (page 292 to 299 in Skene's Elements of Yacht Design) to compare Heeling Moment to Righting Moment. Method #1 is called the "Wind Pressure Coefficient." The equation is:

$$\text{Wind Pressure Coefficient} = \frac{\text{Righting Moment @ } 20^\circ \text{ Heel}}{\text{Heeling Moment @ } 20^\circ \text{ Heel}}$$

$$\text{R.M. @ } 20^\circ = \text{Pounds Displacement} \bullet \text{Righting Arm @ } 20^\circ \text{ Heel}$$

$$\text{Righting Arm @ } 20^\circ = GM \bullet \text{sine } 20^\circ$$

$$\text{H.M. @ } 20^\circ = \text{Sail Area} \bullet \text{Heeling Arm} \bullet \cos^2 20^\circ \bullet \text{Wind Pressure}$$

$$\text{Wind Pressure in Pounds per Sq. Ft.} = .0053 \bullet \text{Wind Speed Knots}^2$$

For comparing boats, a wind pressure of 1 pound per sq. ft. (equal to almost 14 knots) is assumed.

With the assumed heel angle of 20° we observe that sine 20° equals 0.342 and that $\cos^2 20^\circ$ equals 0.883. The Heeling Arm is taken as being the vertical distance from the sails' C.E. to the hull's C.L.R. at zero heel (thus the correction for $\cos^2 20^\circ$).

A Wind Pressure Coefficient greater than "one" shows that he boat has reserve stability given the assumed Heeling Moment. In other words, a number greater than one means the boat would not heel to 20° in 14 knots of wind.

A graph of acceptable values is on page 295 in Skene's . A WPC of less than one reveals that the Heeling Moment is greater than the Righting Moment and the boat will heel more than 20° in 14 knots of wind.

- A small boat may have a WPC of less than one.
- For a medium size keel boat the WPC should be in the range of, say 1.1 to 1.2.
- A large boat should have a larger margin, say up to a WPC of around 1.5 or 1.6.

It is customary with the WPC calculation to consider 100% of the fore triangle, and 50% of the mizzen, rather than true sail areas. This is by convention and allows comparison from one vessel to the next.

Dellenbaugh Angle

A second method commonly used (also given by Kinney) is to derive the Dellenbaugh Angle. It presumes again, one pound of wind pressure per square foot of sail area. The Dellenbaugh Angle equation gives the approximate amount of heel by assuming the Righting Moment at 1° to be constant as the boat heels, and projecting the resulting angle of heel in 14 knots of wind.

From the above W.P.C. it can be seen that the resulting heel angle should be less than 20° for a medium size boat. The appropriate amount of heel for a 30' WL boat would be around 18° to 19° in 14 knots of wind. The graph on page 296 of Skene's gives the appropriate values for boats up to 80' WL.

$$\text{Dellenbaugh Angle} = \frac{\text{Upright Heeling Moment}}{\text{Righting Moment @ } 1^\circ \text{ Heel}}$$

$$\text{Righting Moment @ } 1^\circ = \text{Pounds Displacement} \bullet \text{GM} \bullet \text{sine } 1^\circ$$

(or more commonly expressed as)

$$\text{Righting Moment @ } 1^\circ = \frac{\text{Pounds Displacement} \bullet \text{GM}}{57.3}$$

$$\text{Heeling Moment Upright} = \text{Sail Area} \bullet \text{Heeling Arm} \bullet \text{Wind Pressure}$$

$$\text{Wind Pressure in Pounds per Sq. Ft.} = .0053 \bullet \text{Wind Speed Knots}^2$$

The Dellenbaugh Angle does not accurately predict the amount of heel the boat will have. For example, at 20° heel the RM would not be a linear projection of the RM at 1° heel (it would be less). However the Heeling Moment at 20° would also be less than the Upright Heeling Moment, i.e. the Dellenbaugh equation does not consider the reduction in effective sail area due to heeling. The formula therefore makes the assumption that these two factors will approximately cancel each other out.

The result derived is used as a 'rule of thumb' for comparing one boat to another, and for that purpose it is quite useful as a preliminary gauge of a given boat's sail carrying ability relative to other similar vessels.

Dellenbaugh Angle Notes…

To find the Dellenbaugh angle or the Wind Pressure Coefficient, the ingredient of mystery is deriving a known GM, the distance from the boat's Center of Gravity to the Metacenter.

To find GM, the roll period of a boat can be used for an approximation, or an inclining experiment can be done to get a much more precise result.

Observing the roll period is the easier of the two, and the inclining experiment is the more accurate. They are as follows...

Approximating GM

Roll Period: Roll period is taken as one complete cycle from Port to Starb'd and back again to Port. Roll timing should be done at the dock. Slack lines, calm day, normal trim, no sails set, several trials.

$$GM = \left(\frac{0.44 \bullet WL\ Beam}{Roll\ Period\ in\ Seconds} \right)^2$$

Calculating GM

Inclining Experiment: An inclining experiment is a little more involved. A reasonably good description is given in Skene's Elements of Yacht Design, p. 298.

All tanks must either be totally empty, or must be pressed 100% full in order to eliminate the effects of free surface on the calculation.

Displacement in the as-measured condition must be known, ordinarily by recording the exact immersion and trim, then assessing the lines to determine the exact displacement.

A pendulum is rigged, a weight is moved, the resultant heel angle is recorded. Units used are pounds and decimal feet.

The formula is:

$$GM = \frac{Wt.\ Moved \bullet Distance\ Moved \bullet Pendulum\ Length}{Displacement \bullet Pendulum\ Movement}$$