# The Physics of Apparent Wind

Although many descriptions exist of the apparent wind effect and how to calculate it, often they involve arrows on parallelograms or complicated looking mathematical formulas. This is an attempt to give a simpler explanation!

*Peter K. Taylor, May 2015*

## Contents:



## 1. Introduction: "true wind" and "apparent wind"

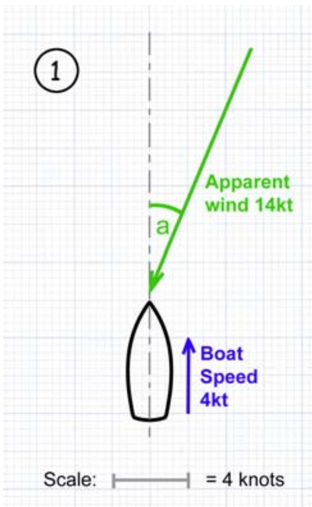
The "*true wind*" is what you feel, and what wind instruments measure, when the boat is not moving, i.e. GPS says that your boat is stationary compared to the earth.

If you start motoring forward on a flat calm day you feel, and your wind instruments indicate, a wind blowing over the boat's bow simply because you are moving through the air. This is "*apparent wind*". If you are moving and there is also some wind, then the apparent wind is a combination of the true wind and the airflow over the bow caused by the boat's movement.

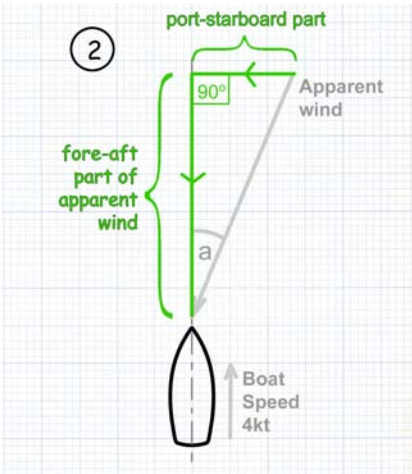
To illustrate how true wind and apparent wind are related, the next section will consider how to calculate the true wind from the apparent wind (and vice versa).

## 2. Converting between Apparent and True Wind

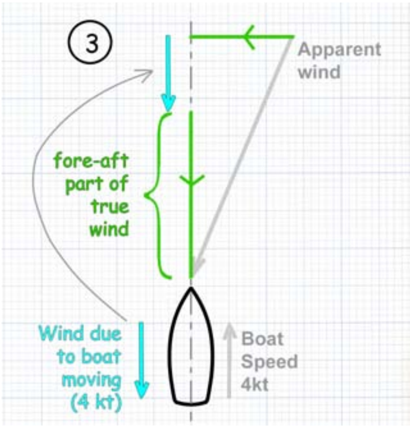
### Case 1: Obtain true wind from an apparent wind which is ahead of the beam




On the boat you know the *apparent wind speed* and *direction* relative to the boat head plus the *speed of the boat*. We will use an example (shown in **figure 1** right) in which the apparent wind is 14 kt and at some angle "a" degrees to the boat's head; the boat is travelling at 4 kt.

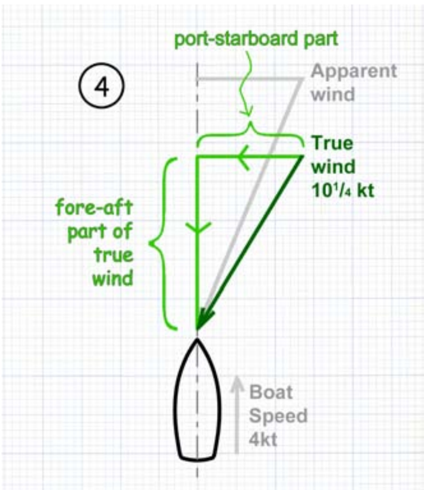



**Step 1.** The boat's motion only changes the fore-aft part of the wind. So we first split the apparent wind into fore-aft and port-starboard components by drawing a scale diagram as in **figure 2**.

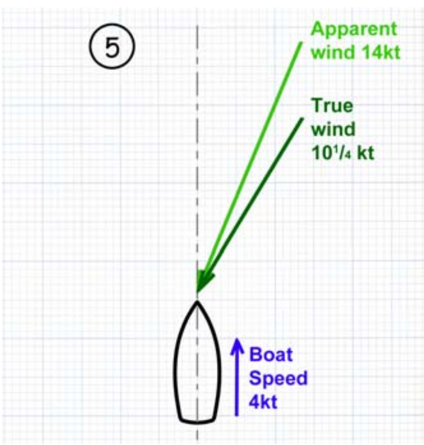



**Step 2.** Now take away the effect of the boat's movement by shortening the fore-aft part of the apparent wind by an amount representing the speed of the boat (**Figure 3**). This gives us the fore-aft component of the true wind.

The port-starboard component of the wind is not affected by the boat's movement, it is the same for the true wind as for the apparent wind.

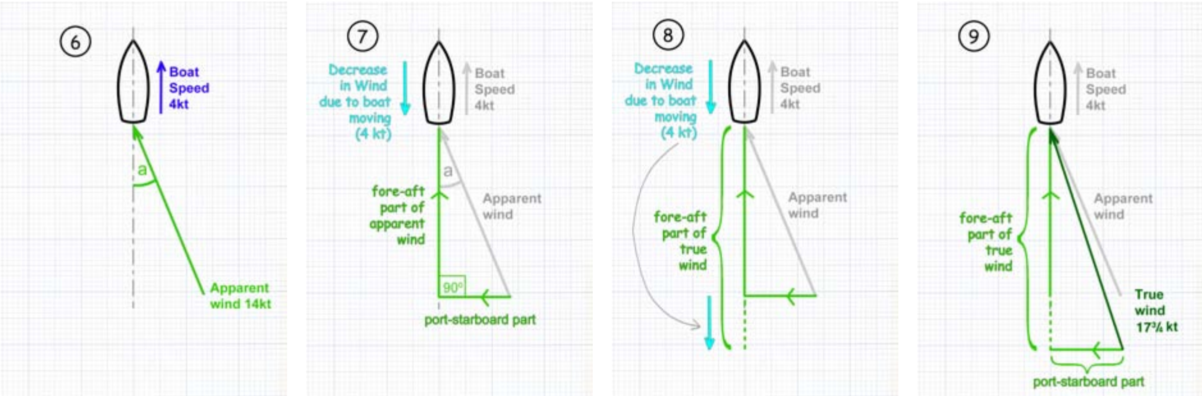



**Step 3.** **Figure 4** shows how to recombine the fore-aft and port-starboard components to find the speed and direction of the true wind.




The result is summarised in **Figure 5**. When the wind is from ahead, the true wind is further aft and less in magnitude compared to the apparent wind.

## Case 2: Obtain true wind from an apparent wind on or astern of the beam




When the apparent wind is from astern the boat's movement through the air will have decreased the apparent wind compared to the true wind. Thus the method is the same except that the boats speed is **added** to the fore-aft part of the apparent wind in order to find the fore-aft part of the true wind. For winds from astern, **Figures 6 to 9** are the equivalents to Figures 1 to 4 (which illustrated the case of winds from the bow). If the apparent wind is exactly on the beam then the fore-aft part of the apparent wind is zero and the fore-aft part of the true wind must be simply equal to the boat's speed.

## Case 3: Obtain apparent wind from true wind

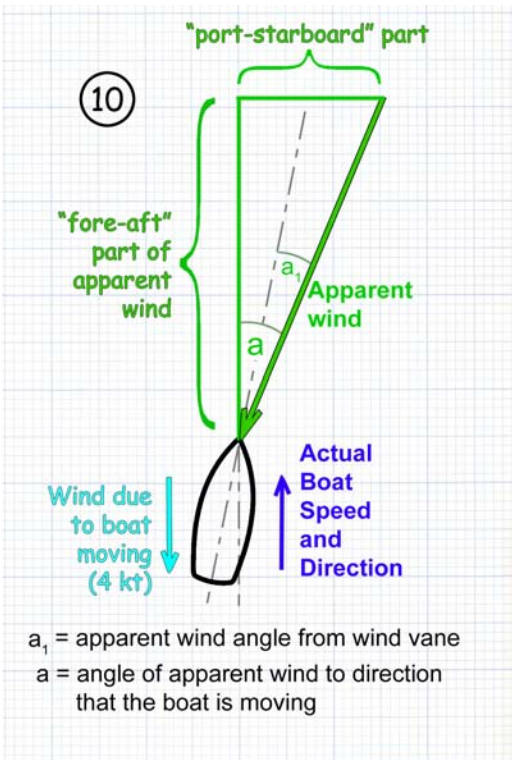
If you know the true wind and want to know what the apparent wind would be when the boat is moving at a certain speed, then the method is very similar. First find the fore-aft component of the true wind, then correct it for the boat's speed, then combine the resulting fore-aft component with the port-starboard component to find what the apparent wind speed and direction would be. In this case the boat speed correction is **added if the wind is from ahead** and **subtracted if the wind is from astern**.

## Case 4: what if the boat is not moving in the direction it is pointed?

If there is a current, or the boat is making leeway, for doing the calculations the "front" of the boat is the bit facing the direction in which it is going, not the bow.

Therefore, draw all the diagrams with "fore-aft" defined along the direction the boat is actually moving and "port-starboard" at right angles to it, as in **figure 10** (right).

The only thing (other than you) which knows that the bow of the boat is actually facing elsewhere is the wind vane. Thus the measured apparent wind direction must be drawn relative to the direction that the bow is pointed and the angle corrected so that it is relative to the direction of motion of the boat.



### Summary: how to remember what to do!

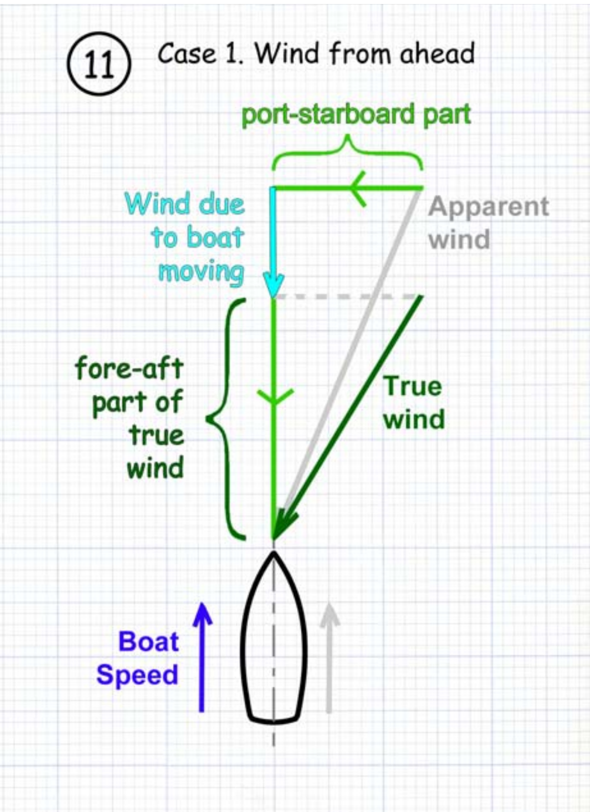
Remember that boat's motion only affects the part of the wind blowing parallel to the direction that the boat is going. Work out what that "fore-aft" part of the wind is, correct it for boat speed, then recombine it with the component of the wind blowing across the boat's course. That latter "port-starboard" component is always the same for both the true and apparent wind.

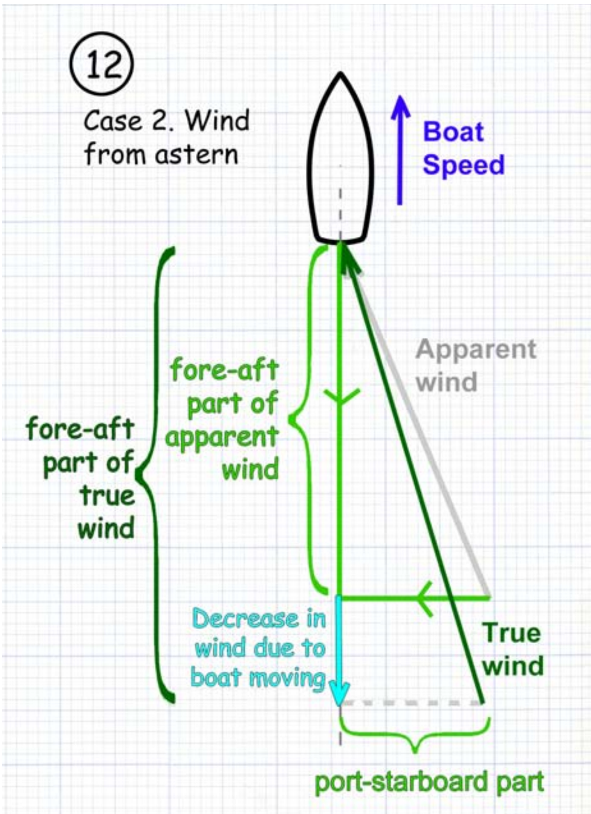
You can remember whether you need to add or subtract the boat's speed by thinking what the wind feels like when you are sailing. Note that the true wind remains the same which ever direction you are facing. However when the apparent wind is from ahead the wind feels stronger so the boat's speed must have increased it. Therefore you must subtract the boats speed to obtain the true wind. When the wind is from astern the wind speed feels less - it has been decreased by the boats speed so the latter must be added to get the true wind.

## 3. Properties of the Apparent wind

### a. The apparent wind is always closer to the bow than the true wind

Provided the boat is going "forwards", the direction of the apparent wind is always closer to the bow than the direction of the true wind. This is shown in **Figures 11** and **12** (below) which summarise the calculation of true wind from the apparent wind for Case 1 (apparent wind from ahead) and Case 2 (apparent wind from astern or abeam)




The difference in wind direction between the apparent wind and the true wind is due to the speed of the boat. It therefore follows that the faster the boat is travelling compared to the wind, the closer the apparent wind will be to the bow.

### b. In gusts the apparent wind direction is further from the bow.

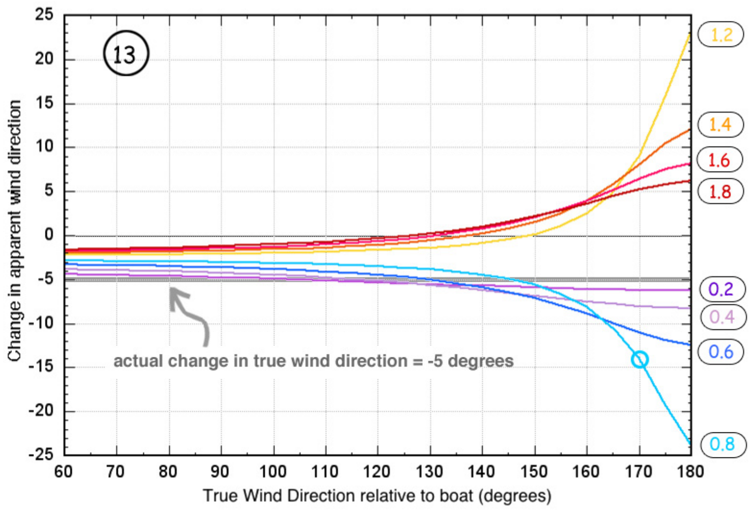
This follows directly from the above.  When a wind gust strikes, the boat's speed suddenly becomes a smaller fraction of the true wind speed,  so the apparent wind direction will move further from the bow - the boat is freed up.  When beating you can take advantage by allowing the boat to bear up towards the wind - often weather helm caused by the boat's heeling will do this for you!

However if you are reaching and a sudden gust allows your boat to plane, then although freed up when the gust strikes, the boat's acceleration will rapidly cause the boat's speed to becomes greater relative to the wind speed.  In that case you may need to bear away to allow for the change in apparent wind during the gust.

### c. The apparent wind direction fluctuates more if true wind is from astern

This is easy to understand if you imagine a boat  sailing directly downwind at nearly the speed of the wind .  The apparent wind felt on board will be more or less nothing because the movement of the boat through the air is cancelling out the fore-aft component of the wind.  In this case, if the true wind direction fluctuates a few degrees to port, the apparent wind will appear to be almost directly on the port beam, similarly a slight fluctuation to starboard will bring the apparent wind onto the starboard beam. So changes of a few degrees in the apparent wind direction would result in a something like a180° change in apparent wind direction!

This effect is illustrated more generally in **Figure 13** which plots the change in apparent wind direction caused by a change in true wind direction of -5° for different ratios of boat speed to true wind speed.




For example, the small blue circle shows the case where the boat is travelling at 0.8 times the true wind speed and the true wind direction is 170° (i.e. 10° on the starboard quarter).  If the true wind direction changes by -5° (i.e. moves slightly further to starboard), then Figure 13 shows that the apparent wind direction changes by nearly 15° and goes even more to starboard.  The various curves show that this magnification of the change in wind direction is most pronounced when the true wind direction is within 20° of the stern, and when the boat's speed is close to the true wind speed.

Because what matters is the true wind direction relative to the boat, the same effect occurs if the boats alignment to the wind alters, for example the stern is pushed round slightly by a quartering sea.  Provided the boat is travelling slower than the wind Figure 13 shows that the change in apparent wind is more towards the bow than the change in true wind - in other words a broach is accentuated by the apparent wind direction becoming more on the beam.

In the case of the boat travelling downwind faster than the wind (ratios greater than 1 in figure 13), then the effect works in the opposite sense with the change in apparent wind being more towards the stern compared to the change in true wind.  Normally this case is purely hypothetical but it could be relevant, for example, if a boat has accelerated due to surfing down a swell from astern.

### d. The apparent wind direction changes with height.

The twist in the main sail is often said to be there to allow for the change in wind direction with height above the water. In fact, in the height range occupied by our sails (say 1m to maybe 8m or 10m depending on your boat) the **true wind direction** is usually more or less constant with height. On the other hand there is a measurable increase in **true wind speed** as you go higher, typically around 15% or so. That means that the boat speed is a smaller fraction of the wind speed near the top of the mast compared to lower down. Hence the **apparent wind direction** is nearer to the bow at the foot of the sail than it is at the top. This change in apparent wind angle is relatively small, perhaps around 5 degrees, but may be important if you trying to sail as close to the wind as possible.

In the photo (right) the twist in the mainsail is far more than the change in apparent wind direction with height - it's main purpose is to depower the sail so I can keep the boat upright!

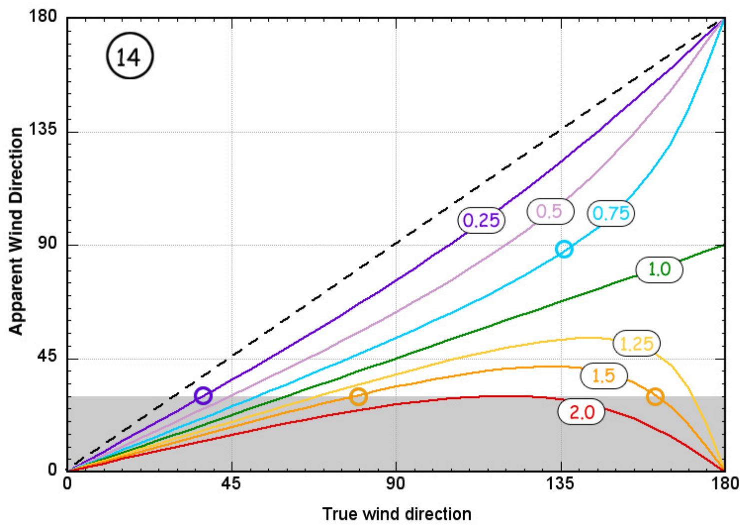
## 4. Sailing faster than the wind.

The sails act like a motor which uses the apparent wind flow over them to drive the boat forward despite the resistance of the water drag on the hull. As long as the driving force of the sails is greater than the drag, the boat will accelerate. The faster the boat sails, the more the apparent wind is increased, and the greater the potential driving force. Theoretically, and indeed in practice, boats can and do sail faster than the wind.

However there is a snag! The faster the boat sails, the closer the apparent wind direction is to the bow. This is illustrated by **figure 14**. The coloured lines represent different ratios of boat speed to true wind speed. Thus, if the wind speed is 10 knots and the boat speed 2.5 knots, the ratio is

$$2.5/10 = 0.25.$$

For this ratio the violet, "0.25", line shows the apparent wind direction for different sailing angles relative to the true wind. It is only when the wind is directly on the bow or the stern that the apparent wind direction is the same as the true wind direction (indicated by the dashed line). For all other wind directions the apparent wind lies below the dashed line indicating that, as we discovered above, the apparent wind is more on the bow.



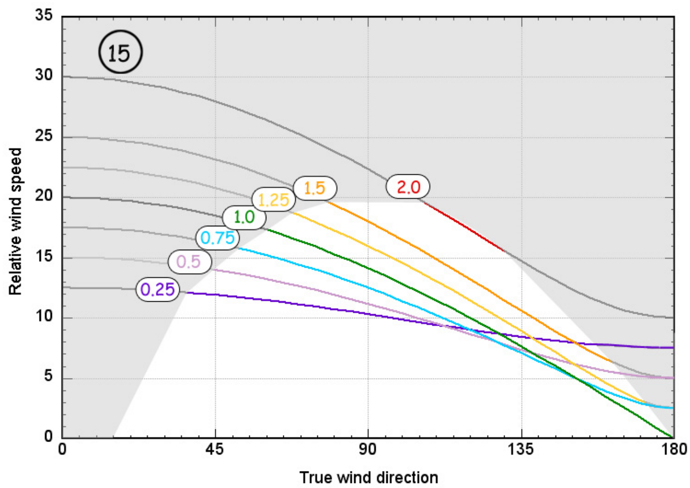

As the boat's speed increases with respect to the wind (larger values of the ratio) this effect becomes more pronounced.

For example, the small blue circle shows that if the boat is travelling at three-quarters of the true wind speed with the true wind direction on the quarter (135°), the apparent direction will be more or less on the beam (90°). If the boat is travelling faster than the wind (ratios greater than 1), then the apparent wind will be forward of the beam (i.e. less than 90°) no matter what the true wind direction.

It's well known that with conventional sails you can't sail directly into the wind. Let's assume that sails will only work effectively in driving the boat forward if the apparent wind is more than around 30° from the bow. The part of figure 14 for which the apparent wind is less than 30° is shaded grey. That means that the boat cannot sail at a speed and direction compared to the true wind which would result in the apparent wind falling in the grey area on the plot. For example the small violet circle on the 0.25 line indicates that if the boat speed is a quarter of the wind speed it cannot sail closer than about 37° to the true wind.

For boats sailing faster than the wind, this apparent wind direction effect becomes a severely limiting factor. At 1.5 times the true wind speed the boat has to sail at between 80° and about 162° compared to the true wind direction (marked by orange circles on figure 14). If it tries to sail at more than 2 times the true wind speed there is no angle of sailing where it won't be headed by the apparent wind. In the most recent America's Cup races the foiling catamarans reached speeds approaching 2 times the true wind speed, Figure 14 suggests why they didn't go any faster!

The apparent wind effect not only limits the maximum boat speed, it also determines what directions can be sailed relative to the true wind.




For a boat which can only sail at 30° or more from the true wind, **Figure 15** shows the possible angles to the true wind direction, and the relative wind speeds, at which it can sail. The true wind speed has been assumed to be 10 knots and the graph shows the relative wind speed the boat would experience depending on how fast and at what angle it was sailing compared to the true wind. Areas in grey represent speeds and angles for which the boat would be trying to sail too close to the wind. The need to stay in the white area by bearing away as the boat speed increases will feel very familiar to anyone who has sailed a fast catamaran or similar craft.

Figure 15 also illustrates one reason that the America's Cup catamarans were set an "up and down" course. In order to be able to foil at speed they could only sail at a restricted range of angles to the true wind.

Thus the apparent wind effect both limits the speed a sailing boat can reach compared to the wind speed, and limits the direction it can sail at speed. To go much beyond twice the speed of the wind is only possible by designing sails (or another wind propulsion system) which provide enough driving force when the relative wind is within 30° of the bow; and/or by reducing what is "enough" by reducing the drag on the vessel. Ice and land yachts achieve much better than twice the true wind speed because for them the drag forces are much lower. Even when the apparent wind is nearly from ahead, and their sails are working inefficiently,  enough drive can be obtained  from the sail to overcome the drag on the craft.

## 5. Practical Summary

While you are actually sailing,  calculating the exact strength of the true wind is neither necessary or practical.  However the following qualitative relationships are worth remembering:

1) The direction of the Apparent Wind is always closer to the bow than the True Wind direction.
2) On a beam reach or close hauled the Apparent Wind strength is greater than that of the True Wind, and increases the closer to the wind the boat is sailed.
3) As the True Wind direction moves aft from being abeam, the strength of the Apparent Wind progressively lessens compared with that of the True Wind.
4) Since the Apparent Wind is much reduced with the wind from astern, think whether to reef before turning onto a beat!
5) When the True Wind direction is well aft, small changes in True Wind direction produce much larger changes in Apparent Wind direction, this makes broaching more likely.
6) During a gust the direction of the Apparent Wind moves further aft allowing you to luff up towards the wind.
7) However hard you sail your Swallow Boat, you won’t go faster than twice the true wind speed!

## Appendix: Mathematical formulae and Spread-sheets

(NB don't look at this section if you don't like mathematics!)

The conversion from apparent wind to true wind can be summarised as:

**Step 1:** convert into orthogonal components along and across the direction of travel:

$[\text{Apparent}]_{FA}$ = [apparent speed] x cos(a)

$[\text{Apparent}]_{PS}$ = [apparent speed] x sin(a)

**Step2:** correct the fore-aft component for boat speed:

$[\text{True}]_{FA}$ = $[\text{Apparent}]_{FA}$ - [Boat speed]

$[\text{True}]_{PS}$ = $[\text{Apparent}]_{PS}$

**Step 3:** recombine the vector components:

[True speed] = sqrt( ($[\text{True}]_{FA}$ x $[\text{True}]_{FA}$) + ($[\text{True}]_{PS}$ x $[\text{True}]_{PS}$)) )

[True direction] = atan( $[\text{True}]_{PS}$/$[\text{True}]_{FA}$ )

**Note on using spread-sheets:** For calculating individual instances of apparent wind and boat speed it is relatively easy to apply the formulae quoted above to get the correct result, especially if you also sketch a diagram. However if you try to write a program or create a spread-sheet it can be difficult to get it to work correctly for winds from all quadrants. Trigonometric angles are defined oppositely from compass directions, and you need to ensure that the trigonometric functions have the correct sign in each of the quadrants. A special tangent function (usually called "atan2") may be available in your spread-sheet package to give the correct value for the angle. And remember that in most spread-sheets the functions require the angle values to be given in in radians, not degrees.

It's necessary to test your program or spread-sheet for all possible combinations of wind and boat speed before you can be certain that it is reliable!