Wind – the invisible engine – by John Ball

What is Wind and why do we care?

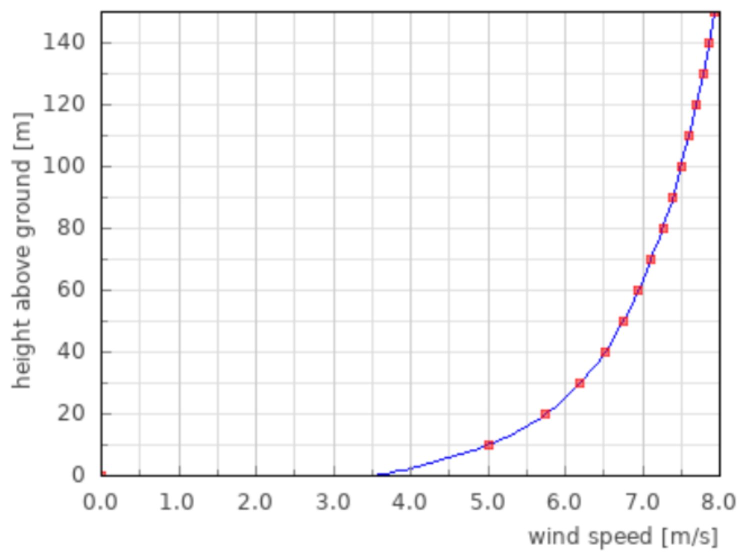
The wind is invisible – we cannot see it, but we can see its effects. Understanding how the wind works will help you understand why your sails are trimmed the way they are.

What causes wind?

Temperature difference causes wind – as the air heats up it expands and becomes lighter and rises. This creates a low pressure area. The colder, denser air is at higher pressure, and moves to fill the low pressure area. This movement of the air mass is what we call wind. The bigger the temperature difference, the bigger the pressure difference, the stronger the wind. On a larger scale, the spinning of the earth causes the moving air masses to spin – called the Coriolis effect – but this is too big a scale to affect our wind for radio sailing.

Wind Gradient

Where the air touches the ground, we call this the boundary layer. As the wind passes over the earth or water surface, the molecules closest to the surface are slowed down by surface friction. As the height above the surface increases, the friction is less and so the wind further up is affected less. We can show that on a simple graph. It shows that the wind builds quickly over the first few feet as height increase, but the rate of increase slows as height increases further.



What is most important is that in radio sailing, we sail in the bottom six to eight feet of the atmosphere, so the difference between the wind at the boom and at the top of the mast is much greater than the wind gradient for a full sized boat where the boom may be eight feet above the water, and the mast head forty or fifty feet above. This means that there is a big difference between the wind speed at the bottom and the top of our sails. The effect of this is what requires us to put twist into our sails, and relatively more twist that a full sized boat. The effect of wind gradient is increased by the 'apparent wind' and another concept called Parallelogram of Forces.

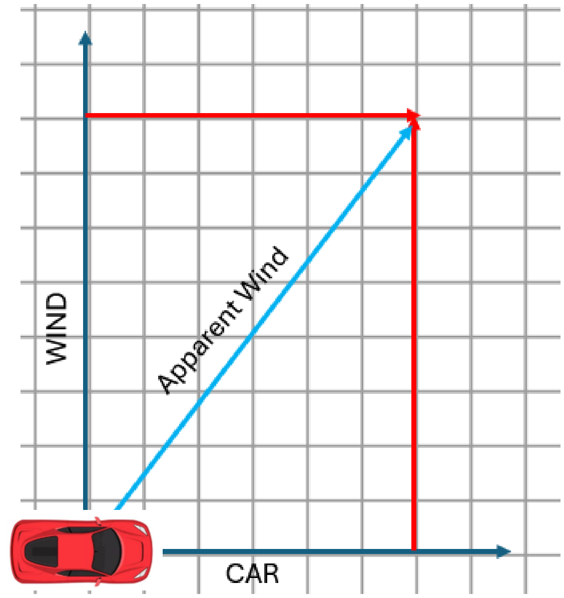
Apparent Wind

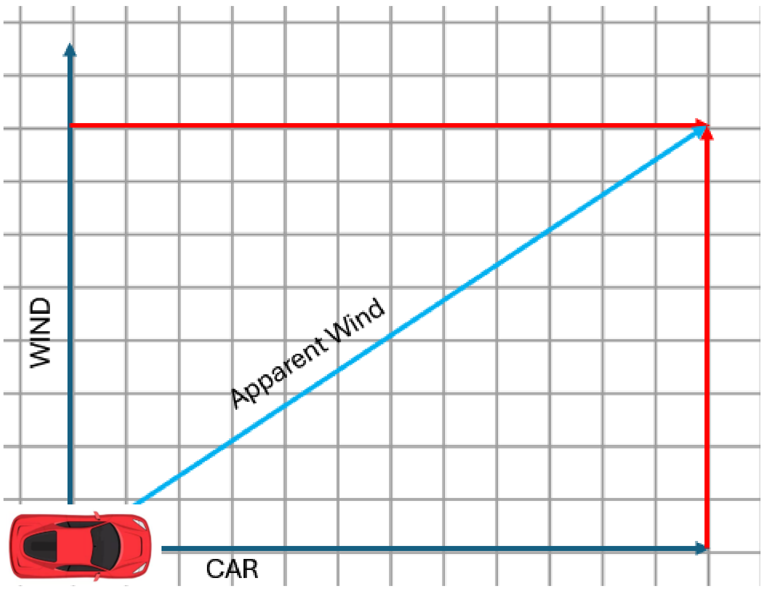
When we stand on the shore, the wind we feel is called the 'true' wind. The wind the boat sails in is referred to as the 'apparent' wind – the combination of the true wind modified by the movement of the boat.

Imagine a car pointing east and sitting still. It has a pennant on its hood. The wind is blowing from the north at 8 mph. The pennant will point into the wind and feel 8 mph of wind speed. This is the true wind. Now the car drives east at 6 mph. What wind direction and wind speed does the pennant feel now? To find the answer, we need to look at a concept called the Parallelogram of Forces.

Parallelogram of Forces

To create a parallelogram of forces, we need to draw a simple diagram of a rectangle where the car speed is 6 units on the X axis, and the true wind speed is 8 units on the Y axis. What the diagram shows is the diagonal of the rectangle and this represents the apparent wind. It shows a line of 10 units length, and its direction is the apparent wind. So the pennant will feel an apparent wind of 10 mph from the direction of the diagonal line. As this is a right angle rectangle, we may use Pythagoras theorem (square root of 6 squared plus 8 squared equals 10).





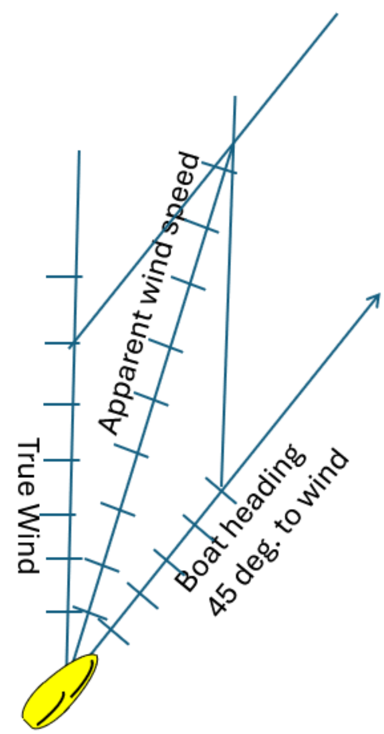
If the car speeds up to 12 mph, while the wind stays at 8mph, the apparent wind moves forward relative to the car, and the new diagonal has a length indicating 14.4 mph.

That is easy to calculate using Pythagoras when the true wind is at right angles to the direction of the car.

Now let's look at a diagram for a sailing example where the boat is close hauled, sailing at 45 degrees to the true wind. This new parallelogram of forces produces a rhomboid. The length of the X axis represents the boat direction and speed, and the Y axis represents the strength and direction of the true wind.

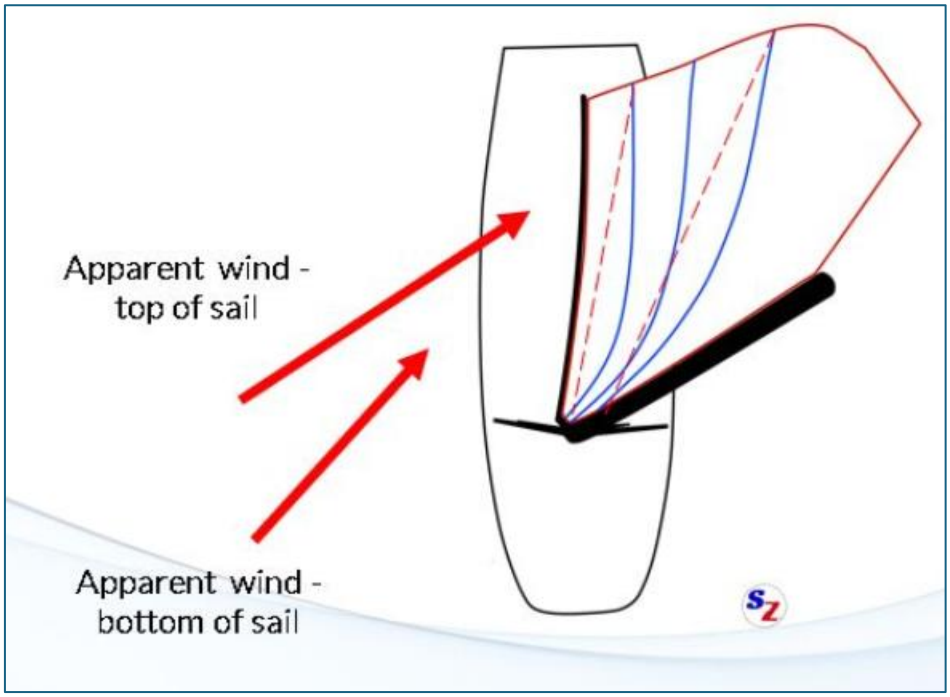
Notice the big increase in the length of the diagonal in a rhomboid which represents the direction and speed of the apparent wind.

In this diagram, the boat is sailing close hauled at about 5 kts, and the true wind is 6 kts. The apparent wind is about 9 kts! (sailing into the wind, you add the boat speed to the wind speed)



Sail twist

Now let's apply the effect of the severe wind gradient difference near the boundary layer where radio sailboats operate with the concept of the parallelogram of forces. The wind at the bottom of the sail will be much less than the wind at the masthead. The length of the red line indicates wind strength and apparent wind direction.



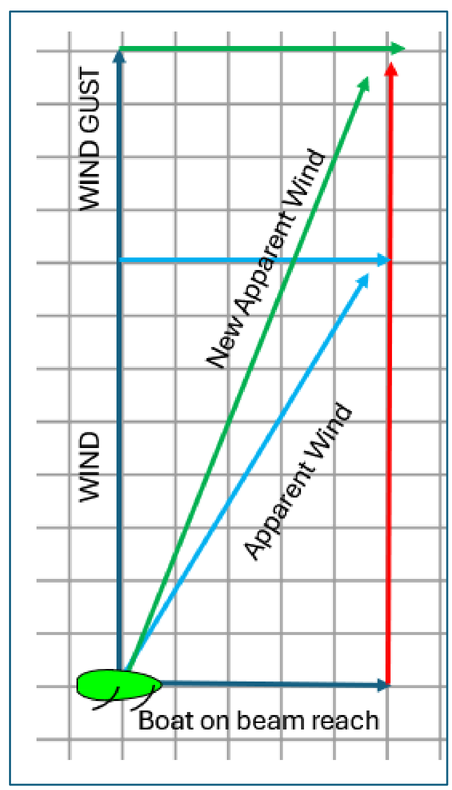
from SailZing.com 1

We want to trim the sails to catch the wind, but the apparent wind at the bottom of the sail will be different from the apparent wind at the top of the sail.

The stronger apparent wind at the top will appear to be further aft – so the top of the sail needs to be twisted off a bit (open leach) or it will stall – and that creates drag – a bit more on this later when we look at how/why a sail works.

Apparent Wind in a gust or lull

Because of the parallelogram of forces effect, in a gust, the apparent wind moves aft and gives the effect of a lift. The opposite happens when the wind drops – the apparent wind moves forward and gives the effect of a header. The ultimate header is sailing into a hole – your momentum causes the sails to luff, just as if you were heat to wind.



In this diagram, we have a boat on a beam reach sailing at 5kts with the wind at 8 kts. The blue line shows the strength and direction of the apparent wind. Now there is a gust of 12 kts and you can see the new stronger apparent wind represented by the green line and as its direction has moved aft relative to the boat, it looks like a lift. If you were close hauled, you would take the lift, and if on a beam reach, you should ease your sails.

It is important to recognise the difference between a gust or lull and a wind shift – in a gust or lull, you do not want to tack as the wind direction is unchanged. However for a wind shift, while you would hold on to a lift, you need to decide if you need to tack on a header.

There are two kinds of shift – Oscillating and persistent. Predicting which one is part science, part alchemy. The important item is to understand the difference as it affects the distance you sail up the course. To help decide which is likely, you need to study the weather forecast for your location – especially the local wind forecast.

Oscillating shifts

An oscillating shift is a repeating pattern, the wind will go left, then right and back again, and sometimes in a predictable way – such as every few minutes, or based on a cloud passing over the course. If the weather system is stable, then it will probably be an oscillating shift kind of day! As we all know, we want to sail on the lifted tack – or do we?

Persistent shifts

A persistent shift is one that moves in one direction continuously during the day. This is usually related to an incoming front – so look at your weather forecast. Persistent shifts are usually measured in hours and are not normally an issue for radio sailing, as we may finish a leg of the course in just a few minutes – not enough time for a persistent shift to have much effect. But they do exist and when one is happening, we need to recognise it and we want to sail the headed tack first! And remember that the last tack into the mark is always a persistent shift as there is no time for the wind to go back!

Your local weather

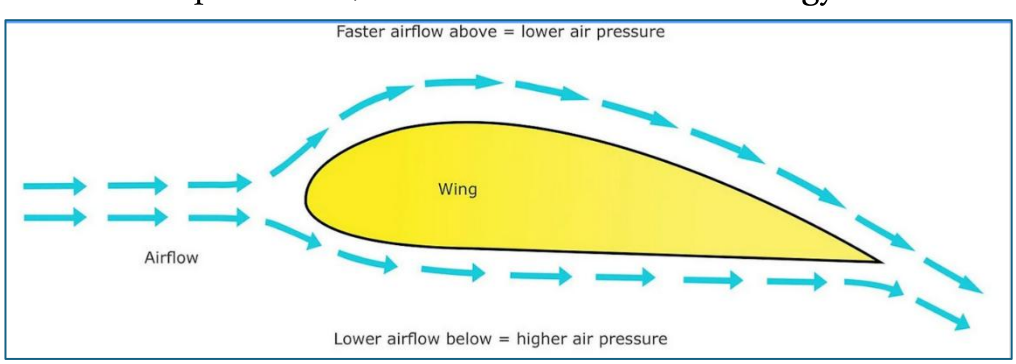
You may live in an area blessed by stable prevailing winds, or an area subject to rapid changes with approaching fronts. Some locations have a repeating pattern of wind as the land heats up and a thermal sets in which may reenforce the prevailing winds (hold on to your hat), or come from the opposite direction. When this happens we usually experience a convergence zone – an area between the two opposing winds, and the result is a gap with no wind. What is important is to know your area, and study the weather forecast before leaving home.

A couple of sites specialise in providing detailed wind information and you may select your location.

https://www.windfinder.com https://www.windguru.cz

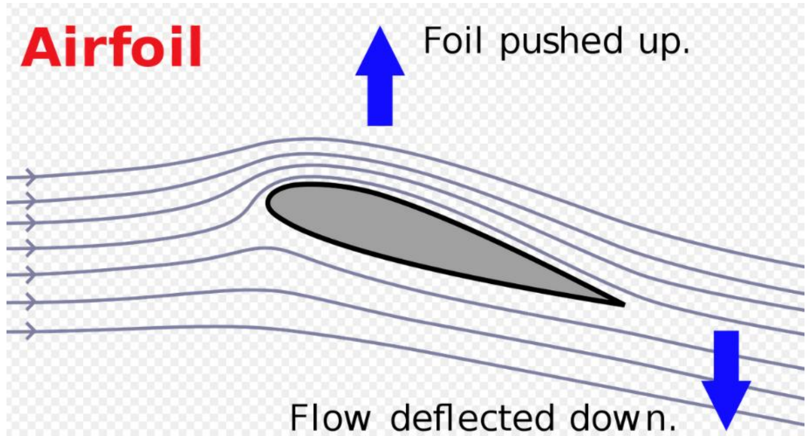
How a sail generates force

A moving air mass has kinetic energy – the energy of momentum. We call it wind. We have looked at what causes the wind and how it can affect how we shape our sails, but how do we extract the energy from the wind? The answer is that we use the sail to bend the wind – and the more we bend it, the more energy we extract – but there is a limit – bend it too much and the airflow stalls and breaks down and that causes drag. This diagram shows how much the airfoil is bending the wind – look at the direction of the airfow as it approaches and exits the foil.



We think we are familiar with how an airplane wing works. The wing surface is curved – an airfoil – and approaches the airflow at a slight angle – the angle of attack. But how a foil generates lift is complex. There are several different theories of how an airfoil generates lift

One is based on Bernoulli's principle, where the air flow splits, and some of the air going over the top of the airfoil has to accelerate as it becomes compressed. That acceleration creates a low pressure area above the wing, and the higher pressure below the wing pushes up in an attempt to equalise the pressure. So basically the wind above the wing sucks the plane up – we call it 'lift'.



Another theory is based on Newton's third law "For every action, there is an equal and opposite reaction." The air, in reacting to the airfoil's downward deflection, exerts an upward force on the airfoil.

Yet another approach (curtesy of Lester Gilbert's site https://www.onemetre.net/) is to imagine a bundle of fluid particles as flowing over the upper surface of a cambered wing. Starting from the nose, the particles are forced up by the curve of the wing. As the curve of the wing eases off, they stop being pushed up, and travel straight and level for a moment or two. And now as the wing surface begins to drop away, where do the particles go? Well, they just want to keep going straight because of momentum and inertia. On the other hand, if they all just stop following the surface, it will create a perfect vacuum. So some of the bundle starts to follow the surface down, some of the bundle continues more or less straight on, and the remainder of the bundle spreads itself between those two. Technically, this results in decreased fluid pressure on the upper surface. A pressure decrease is the same thing as a partial vacuum, meaning that there is a suction on the upper surface of the wing, lifting it up.

Some scientists argue that there is a combination of various theories at work.

A sail works in much the same way as a wing, except in the vertical – the air accelerates or is bent around the lee side, creating a low pressure area, and the high pressure on the windward side tries to compensate. The dynamics of the sails, hull and fin interaction are complex and beyond the scope of this discussion. In simple terms, the wind pushes the boat sideways and the fin in the water (which is much denser than air) resists that sideways push. This has the combined effect of propelling the boat forward - think of squeezing a lemon pit between finger and thumb – it shoots out!

In conclusion

In closing, this article did not talk about tuning, or sail trim – many have done that already. Instead this article set out to help you understand how the wind works. That understanding and consulting your local weather forecast will give you some additional tools to have a good day sailing and racing.