Navigation with Leeway

Leeway, as we shall use the term, means how much a vessel is pushed downwind of its intended course when navigating in the presence of wind. To varying extents, knowledge of this effect is crucial to the navigation of any vessel, sail, power, or paddle. On the other hand, if we have a functioning GPS and know how to use its special features—or better still, a GPS and an electronic charting system (ECS)—then the concept of leeway really does not matter that much. We can read from the GPS our course over ground (COG) precisely, which is the actual direction we are progressing regardless of what the compass says, and we can navigate accordingly. On one level, we don't care what causes our course to be what it is, we just need to know what it is.

Furthermore, it is even fairly rare that your COG would differ from your intended course by leeway alone. Usually there are several factors causing you to make less progress to weather than anticipated; leeway is just one of them. But there are cases where leeway is the dominant factor, and furthermore, the existence of GPS and ECS has never been a good reason to not learn as much about navigation as we can. First, the GPS can fail (rare but possible), but more fundamental than that, even if it does not fail, GPS cannot tell us the best way to get from A to B. To choose the best route from A to B takes knowledge of navigation, and leeway is part of that knowledge.

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The term "leeway" comes up frequently in maritime discussions, but the practical meaning of this word depends on the context. Usually it means how much a vessel slips to leeward as it progresses along its course *under normal operating conditions of the vessel.* In this case it is an unwanted error in the course reckoning that we must account for. This is the meaning most navigators have in mind. We might call this "normal leeway."

When you are in a vessel under *special conditions,* such as just drifting in the wind, then "leeway" has a special meaning. In this case all of your motion is leeway, not just part of it. We might call this "drifting leeway." Much writing and discussion of "leeway" typically does not distinguish between the two, but they should. They are very different concepts. Normal leeway and drifting leeway behave very differently with changing variables. Search and rescue teams care about drifting leeway; navigators care about normal leeway.

Yacht designers, on the hand, have still a third definition—or at least it seems to be different. Their's is a complex one, related to hull, keel, and sail performance. Refer to yacht design books to learn about how they define this and the key role it plays in the design of a yacht.

From here on in the present discussion, "leeway" means "normal leeway;" it is how much the boat slips to leeward when progressing under normal conditions. For a sailboat this means under sail with normal rigging; for a power boat, it means under power. We are further talking here mostly about sailing vessels, but powerboats will have to measure this and make corrections as well. For power boats it depends very much on the type of boat, the amount of windage, and the average speeds.

The most important point about leeway for navigators to appreciate is leeway is real motion *through* the water, as opposed to the effects of current, which is motion *of* the water. You can read the effect of leeway on your knotmeter; you cannot see the effect of current on your knotmeter. If your knotmeter says you are going 6.5 kts, then that 6.5 kts is a combination of the intended design performance of the boat for that wind speed, or RPMs under power, and some contribution from the wind pushing you sideways downwind. The amount of the push to leeward is some few degrees to some 15° or so for a well designed sailboat, depending on factors we will discuss in a moment.

When sailing dead down wind, the concept of leeway has little meaning. The course you make good is the course you are steering. In a sailboat it is hard to think of the concept of leeway in this case as anything other than just your speed for the given wind. In a slow, high-windage trawler you still have some semblance of the concept, in that downwind in flat water in 15 kts of wind you will go faster than in 5 kts of wind for the same RPM. Kayakers know this reality much better than power boaters, where the effect is dramatic. Likewise, the reverse is true. These effects are actually very large in low powered vessels. Direct downwind and upwind, however, are bordering on the concept of drifting leeway. What ever we learn about this upwind and downwind behavior will not translate very well to traveling diagonally across the wind.

Furthermore, the direct upwind and downwind conditions are often strongly influenced by your vessel's interactions with the waves. Pounding into the waves slows you down, surfing down the waves speeds you up. In medium to large seaways the effect of waves could be a bigger effect than the "windage."

So normal leeway is not a consideration when travelling straight into the wind or straight down wind. If you want to make a dead reckoning plot of your travel in these cases, you just use your indicated compass heading and your indicated knotmeter speed to lay out your track.

Sailing across the wind is another matter. It is difficult to make accurate predictions of what the leeway will be for a sailing vessel, sailing close hauled. A first guess *in ideal conditions* would be to take what the yacht designer says it should be for your boat and then double it! Again, they have a different concept of leeway than what transpires in the real world of navigation. Move from ideal conditions and even this does not work. All bets are off. They might show numbers such as 1.4° of leeway at say 12 kts of wind, etc, but unless you are an Americas Cup yacht in perfect conditions you will always slip way more than that.

The key point here is, we can measure it. It is real motion through the water, so you can see it (Figure 1), and if you cannot see it, your GPS chart plotter can see it (Figure 2). If you look back while holding a very steady course, you can sometimes discern your wake kinked up to windward, which is the effect you get as you slide to leeward. That is the angle you want to know. Visual measurements are difficult, however; this is best measured electronically. The effect is much easier to see when standing on a dock watching boats sail away from you. Folks living on house boats where there is a lot of sailing in sight in various wind conditions day after day might be the best to do a study of leeway!

Figure 3 shows how you do this with an ECS track of positions. The leeway angle must be recorded for the conditions at hand, meaning point of sail, sails set, sail quality, wind speed, sea state. All of these can matter. Sail trim and helmsmanship can also matter in a practical sense—at least they will matter to in your actual progress to weather, as shown in the sidebar below on Sailing with Leeway.

Each of those factors listed change the leeway for the same boat. From boat to boat there could be even larger changes. As a rule the dominant factor is the depth of the keel, maybe even more than keel shape, but the aspect ratio of the keel can also cause up to a factor of two difference in leeway. A full keel boat will slip less than one with a fin keel, but a deep fin keel will slip less than a shallow long keel. There are no dependable single rules; you just have to measure this. Some navigation books offer tables of guidelines for leeway corrections, but leeway is so specific to so many factors, it is hard to imagine such tables could be a useful solution.

But there are some general guidelines. First leeway in a well-designed sailboat is almost entirely limited to sailing close hauled. Fall off 20° or so and most of it is gone. Next we know roughly how it behaves with wind speed. Starting from your vessel's ideal conditions, say 12 kts of true wind, then the leeway will increase from there as the wind builds. So if it starts at say 4° at ideal wind, it might build to some 15° at 20 kts or so, and could be even bigger in stronger winds. But it generally will not get much bigger than about 15° because at some point you just fall off, and once you fall off just a point or two from close hulled, the leeway drops dramatically, so there is some practical upper limit to what you will experience underway, even in the worst conditions (see side note on Sailing with Leeway).

What may be more of a surprise is the leeway increases as you go to very low winds. In the hypothetical example just given, if we dropped to 6 kts of wind, the leeway would decrease, but at some point of siling in very low wind it will actually begin to increase again, because many boats are just not very efficient at low speeds. Again, guesses or estimates are no replacement for actual measurements. Typically it is only racing sailors that might care about this important low end behavior, because anyone else would just turn the engine on at 2 kts of true wind!

The best measurements are made when there are no currents. Currents confuse the issue enormously. So try to get data when sailing in no current. Then just compare your GPS track of positions with your heading on each tack into the wind. Note the results along with all of the conditions mentioned above, and start a table for various wind speeds. Often you have the same trim and sails for a given wind speed, so the wind speed alone is a record of the conditions you need to know.

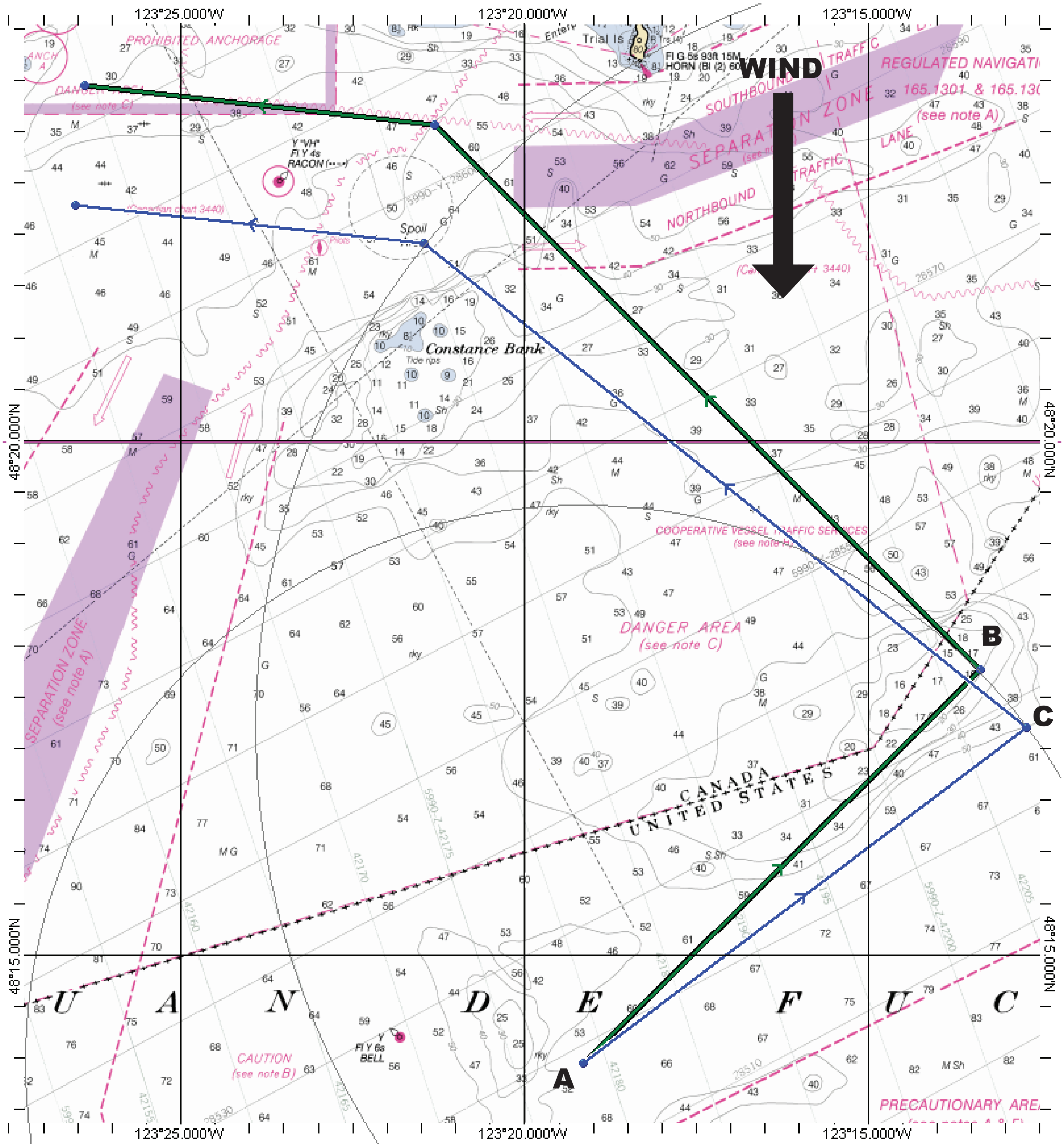
It is very important to know this for calling the more efficient tacking angles in high winds and in very low winds. If you think you are tacking through some 90 or 95° according to the compass headings, you may find that the reality is more like 100 or 120°. Remember it is the high winds and very low winds where the leeway is the largest.

Recall the trick we use elsewhere in the course to analyze the effect of angles, the "small angle rule," or "6° rule," or whatever you want to call it. Namely with a 6° error in your heading you go off course 10% of your distance run (Figure 4). After sailing what you thought was due north for a mile, you would be 0.1 mile off to the side if your heading error were 6°. If your error were 3°, you would be off by 5%; if your error were 12°, you would be off by 20%, and so on. The leeway is important to keep in mind when making a DR plot that you want to correct for the best possible estimated position, or for calling lay lines for a tack. See Figure 3.

Leg	Name / Position / Elevation	Bearing	Distance	Ascent	Time
0	WP0501 48°13.944'N, 123°19.150'W				
1	WP0502 48°17.767'N, 123°13.373'W	045°T	5.43 NM	0 ft	1:48
2	WP0503 48°23.067'N, 123°21.313'W	315°T	7.5 NM	0 ft	2:29
3	WP0504 48°23.451'N, 123°26.404'W	276°T	3.41 NM	0 ft	1:08
		Totals:	16.3 NM		5:26

Leg	Name / Position / Elevation	Bearing	Distance	Ascent	Time
0	WP0501 48°13.944'N, 123°19.150'W				
1	WP0602 48°17.215'N, 123°12.702'W	052°T	5.41 NM	0 ft	1:48
2	WP0603 48°21.916'N, 123°21.457'W	308°T	7.5 NM	0 ft	2:30
3	WP0604 48°22.287'N, 123°26.538'W	276°T	3.41 NM	0 ft	1:08
		Totals:	16.3 NM		5:26

Route Card output from Memory Map Navigator. Top is route without leeway corrections, bottom shows 7° leeway on windward legs, none on last leg which is off the wind. The two routes are plotted out in Figure 3.



Prepared with Memory-Map

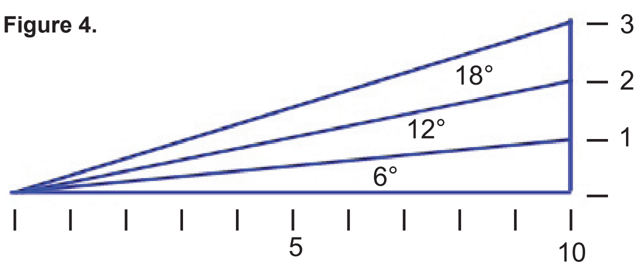
Figure 3. *MM-Nav plot of sample route. Two tacks to close hauled weather (wind from due North) then some 39° off the wind, which would probably eliminate most of the leeway. To correct a DR leg such as A to B for leeway, you plot it the same length but just rotated downwind by the leeway angle. Here the uncorrected leg is at 045T, the corrected leg at 045+7 = 052T. You have to know what the leeway is for each wind speed and other conditions for your vessel. Usually, it would be the same for both tacks in a given condition, but you might learn that even this is not true if the waves are not running in line with the wind. Note that we can use the small angle rule to estimate how much C will be off of B for 7°. The distance A to B is 5.4 nmi. The rule tells us 6° is one tenth offset, which would be 0.54 nmi, but we are a bit higher (7/6)x0.54 = 0.63 nmi. Checking the chart you see the distance from B to C is about 0.68, which is consistent with the approximations.*

Figure 1. *Sailboat wakes... not really showing much! The two left are essentially straight aft. It is light air and they are both cracked off the wind, so we would expect them to be straight. If we were to detect any leeway visually, they would have to be closer to the wind and the wind stronger. In that case, the two lines shown would be leaning somewhat off to the left, upwind. We might still see a few degrees in the ECS track however, even when not at all visible by eye.*

The top right case is a candidate for showing the effect, but not for certain, it would not be this big. These are race boats and their heading is changing often to match puffs of wind, so we may have caught them off course a bit—but this is sort of what it would look like. It would not be this big however (shown is about 17°) these are high tech boats in what is still relatively light air. They will not slip more than 3 or 4° in these conditions.

If you do get the rare chance to actually see this visually, keep in mind that a finger width at arm's length is about 2°, which is a crude way to estimate the effect.

Figure 4.



Small angle Rule. *A right triangle of 6° has ratio of sides = 1:10, and this can be scaled up to 18° or down to 1°, which if often useful in many aspects of marine navigation.*

Sailing with Leeway

Several places we have noted that there is a practical limit to the leeway you might experience when sailing to weather. Here is note on how this comes about.

As the wind builds, the leeway builds as long as you stay close hauled. If you duke it out to stay hard on the wind into say 30 kts or so, you might be looking good on the compass, and in fact pointing higher than a neighboring boat, but chances are you are slipping to leeward some 15° or more. Thus your progress to weather is not at all what you think it might be.

If your destination is due north and your heading is 045 T making 7 kts, you might guess your progress to weather was about 4.9 kts (7 x cos 45), but in reality you are slipping to leeward 15° so your course made good is some 060 T at 7 kts. Your actual progress to weather is more like 3.5 kts.

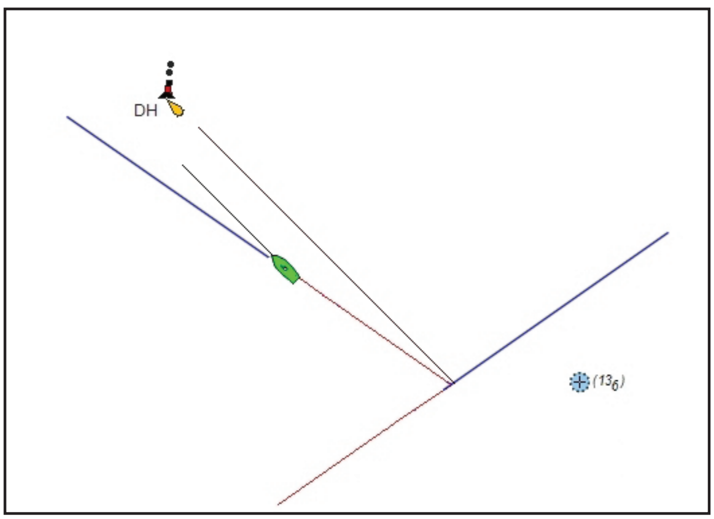
Now if you give up the fight and fall off 15° to a course of 060 T, you will have lost most or all of the leeway and actually be making good the 060 you are steering, but off the wind you will also pick up speed, maybe a knot or more. Lets say it goes to 8 kts. Then your progress to weather is 8 x cos 60 = 4.0, so you have gained half a knot. In practice your gain will be higher than this.

In the old days of sailing when leeways were much larger because the boats were not as efficient (a couple points or more, 20° to 30°), they had a saying to remind us of this steering correction: "Keep your wake right astern."

To read one treatment of this from the golden age of sailing see Lecky's, *Wrinkles in Practical Navigation*, page 664. We have made this link to get you a copy of this great book:

www.tinyurl.com/1918Lecky.

First edition was early 1800s, but later ones are better. Last edition was 1947, I believe.



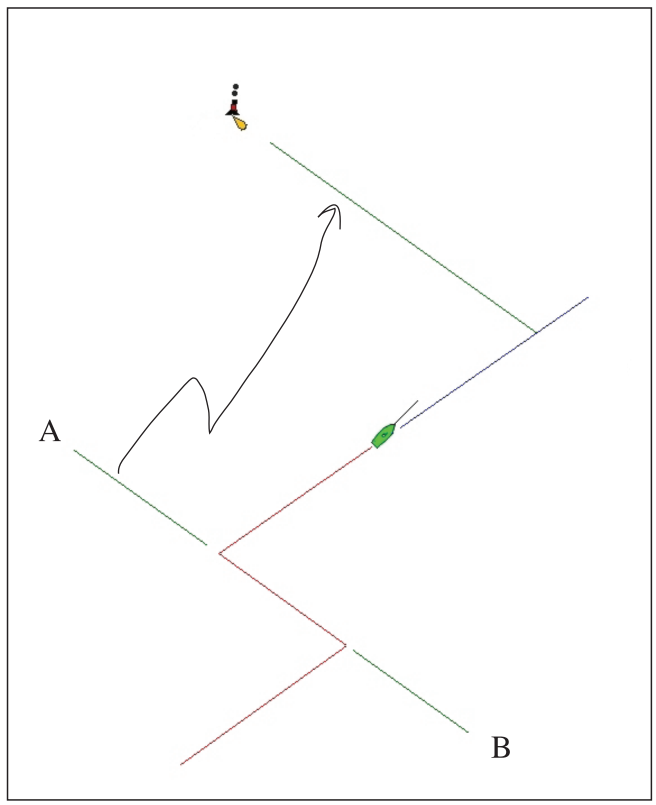


Figure 2. left. *Vessel track (red) on an ECS display showing the vessel heading line indicator (black). This boat is tacking trough 90° according to the compass, but is actually tacking through 120 degrees because of leeway. In other words, check the compass reading just before a tack, and the new reading after the tack will be 90° different. BUT, if you see your target on the beam, and then tack to head toward it, you will only be pointing to it for a short time, as you slip down wind. If the target you tack toward in this way is a long way off, you will not note your error visually for a long time, but it should show up quickly on an ESC plot like this one. The normal procedure is to make several tacks ahead of time so you can judge your true tacking angle, then just move one of those lines to lay on the target to know when to tack and really get there.*

Right. *Judging tacking lay lines with leeway. The red line is your history of two tacks showing your true tacking lines. Use an electronic range line to copy the line AB to the mark you wish to tack toward, then project your present course till it crosses that line, and that is when you tack. With this layout and your know SOG you can then predict the tack time very accurately so everyone is ready.*