Bad News for "Velocity Made Good"

Craig Summers, the developer of The Sailing GPS, shows how Velocity Made Good is at the root of some common sailing problems.

Velocity Made Good, or "VMG", is the measure of speed towards your target. On a winding path, VMG is like a vector measuring a straight line to your next mark, with movement in other directions separated out. It seems like a clever approach for obtaining your actual progress towards your destination. Sailboats tack back and forth, which should make VMG very useful.

Even for experienced sailors, it is difficult to judge the best balance between getting speed off the wind and shortening the distance by pinching close to the wind -- particularly if your destination is not directly upwind. So you head onto a tack, getting the telltales flying just right and evaluating the Estimated Time of Arrival (ETA). However, many sailors may have experienced a puzzling phenomenon with the ETA on GPS units and chartplotters. Right when you need it most to judge whether you have an effective tacking angle, all of a sudden the ETA goes blank! It is actually designed to do this. Read on to see how Velocity Made Good is at the root of it…

Time in Sailboats Let's start with a few examples from personal experience of times when it would have been really good to know an accurate arrival time. Some readers may know that The Exumas island chain in The Bahamas is a beautiful sailing spot, with endless shallow flat turquoise water, as far as the eye can see. When returning from The Exumas to Nassau, it is possible to save a day by doing a long diagonal route from Norman's Cay to Nassau. This is an all-day passage with a distance around 50 miles, so you have to leave early. For sailboats, it has to be a straight shot; there is not enough daylight to add any tacks.

Ordinarily this is an idyllic passage in either direction, with good steady wind power, and clear turquoise water over a sandy bottom. But one time as we headed northwest back to Nassau harbor, the wind gradually came around to our nose while we were still perhaps 25 miles out, turning our broad reach increasingly into a beat. In order to maintain speed, we would have to head off. The cost of doing so would be an additional return tack of perhaps 7 or more miles. Thus arises the question: How long will it take, if we pinch tight to the wind at a lower speed? Or is it better to do the further tacks and maintain optimal speed?

I check the GPS chartplotter at the helm. With a big graphic screen, it cost nearly $1000 and shows the rhumb line like a laser beam from our starting point straight to the harbour entrance. However, as I start to head off, the ETA goes blank. Hours later, we are still reassuring guests and crew that "it won't be long now", while there is really no way to tell exactly how long we've got before the second tack, or if we are going to make it in before the sun starts getting low.

whether tacking upwind on a keelboat or a catamaran the skipper needs to judge a tacking route that will provide the shortest arrival time

Another year, I am getting just as much enjoyment laying across the floor of a 9-foot sailing dinghy, sailing in a cove in St. Margaret's Bay, Nova Scotia. With its tired duct-taped sails, forward mast and small centerboard, the boat doesn't point high to the wind. I only have perhaps 1500 yards upwind to the wharf and dinner, but my choice is to plod along with the sails hauled in making marginal progress, or to go for speed across the wind, at the cost of dozens of tacks in the little bathtub boat. That would substantially increase my distance. To make matters worse, on the angle to the wind that gives my best speed, I am barely a few dozen yards closer to the wharf on each tack back. And I don't want to miss dinner.

Velocity and ETA While On a Tack

Whether in a big new cruising catamaran, a keelboat or a Nutshell Pram, the same question arises. The dilemma of choosing the best tacking angle has been around for as long as sailboats have been able to tack upwind. Given a particular boat's pointing abilities, how do we get the best balance between good speed and reduced tacking distance? This article originated in discussions of whether ETA is based on speed or VMG with Gregg Babish, a Geographic Information Systems/Data Manager, who sails with his wife on a restored Chrysler 26 (http://users.accesscomm.ca/gbabish/).

We're sailors; we don't travel straight to a destination. We zig-zag. It is lift on the sails that allows us to travel up wind, or theoretically to even travel faster than the wind. However, the classic sailor's dilemma is to try to get the perfect balance between speed and distance on a tacking leg. That will give you the shortest Estimated Time of Arrival (ETA). Since many GPS units and GPS chartplotters display ETA, it is logical to assume that ETA is being calculated accurately on that pricy chartplotter device in your cockpit. Heck, the GPS is tracking your exact location to within yards, from satellites out in space, so the ETA should be pretty good, you would assume.

However, as you head out on a tack, maybe you have had a nagging feeling about ETA. You may have wondered what Estimated Time of Arrival (ETA) means, when you are tacking. Does ETA mean in a straight line to the destination with no tacks? Does it recognize the excellent speed you are getting while on a beam reach, or think you are off course? How does it know when you are going to tack? And why don't marine GPS manuals include a section on sailboat tacking to explain all of these things? With all of these questions, perhaps ETA is not quite as accurate as it seems.

Velocity Made Good could be the ideal solution, however, it is kind of a technical topic. The kind of thing where you skip all the fine print in the GPS user's guide, or where people's eyes glaze over when mentioned in casual conversation. Many sailors may not be aware that VMG contains an inherent flaw. As your tack takes you farther from the "rhumb line" (the straight line to your destination), the VMG gradually decreases.

Even while you maintain constant speed and heading, if you keep watching the VMG it is continually decreasing on its own. Even if your speed and heading remain constant, VMG progressively decreases the further you get from the rhumb line (i.e., as cross-track error increases). Sailors need an accurate way to estimate arrival times, and to know they are on the best tack. But this is like having a speedometer in your car, and as you go down a straight highway at a constant speed, the speedometer needle continuously falls the farther you drive.

This seems to be caused because a destination upwind becomes increasingly off your beam the longer you tack, until eventually you would be going away from it. While it seems paradoxical, the effect is happening even when traveling small distances off the rhumb line. Velocity Made Good will therefore decrease all the way to 0 when your destination is at 90 degrees to your heading and is directly off your beam. If you are in a boat that doesn't point very high into the wind, or the destination is not directly upwind and you need to continue on the same tack, the Velocity Made Good actually then goes into negative numbers (see Figure 1).

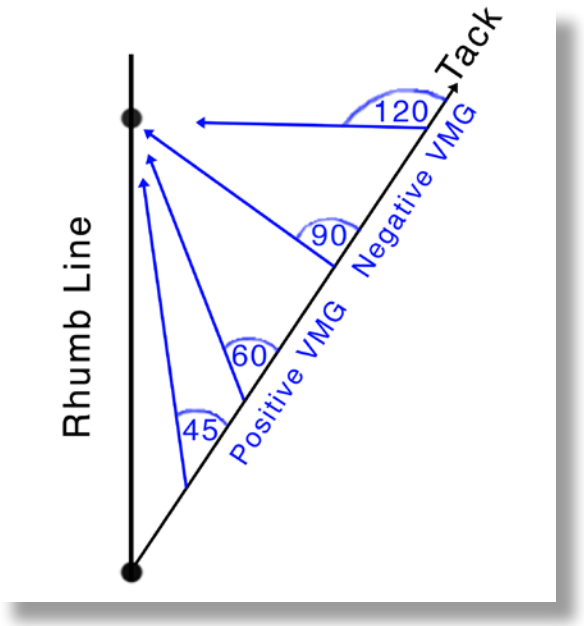

Figure 1: As a tack continues, the destination is increasingly off the beam of the boat at 90 degrees. As the degrees increase, you are increasingly heading away from your destination. Velocity Made Good is therefore continuously decreasing while you stay on the same tack at the same speed.

Why does ETA go blank when on a tack?

VMG erroneously gives the illusion that you are heading increasingly off-course or slowing down, even if you are on the correct tack and your speed remains constant. That seems to be why all GPS manufacturers blank out the ETA when you start tacking. This was actually the reason prompting the development of The Sailing GPS, to find a method to display the correct tacking times and distances -- and one that would not purposely blank out when you needed it most.

Normal GPS chartplotters are actually designed to go blank when tacking. Why? It is probably because the standard GPS method of calculating the ETA is based on velocity made good (VMG). Superficially, this seems like a clever idea: calculate your estimated time of arrival accounting for how much you are off-track. Unfortunately for sailors, the only way to do this is with Velocity Made Good, which is continually deflating all by itself as you continue on a tack. So as VMG becomes less reliable, ETA is blanked out.

Thus our explanation for why ETA goes blank on standard chartplotters. It is not that you are considered to be off-course; it is that VMG becomes a worse and worse predictor of arrival time. It is better to use speed. Then calculate distances using trigonometry in order to project arrival times, which is what The Sailing GPS does automatically. When tacking, VMG provides erroneous readings of velocity and ETA and should not be used for navigation.

Inconsistent Estimates of Velocity and Arrival Time

Perhaps some manufacturers would argue that in their internal methods, ETA is in fact not calculated based on Velocity Made Good. Even so, VMG is of very questionable value for sailors (and windsurfers). The projections are erroneous, and the errors get larger the longer you are on the same tack. If you are racing or just trying to estimate your arrival time, you may have the temptation to estimate arrival time based on VMG. But if you did this at the beginning of your tack, your VMG might be 6 knots. Half an hour later, with the same speed on the same tack, your VMG might be 1.5 knots. VMG does not provide consistent measures when on a tack. For this reason, it is mathematically

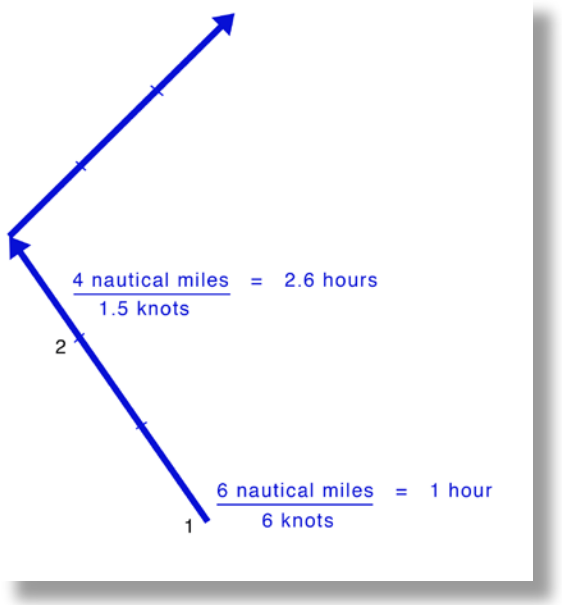

Figure 2: Flawed attempt to estimate arrival times using Velocity Made Good, with two tacks of 3 nautical miles each. When beginning the tack at Point 1, the target is 40 degrees to starboard (VMG = 6 knots). Later at Point 2, the target is about 80 degrees to starboard (VMG = 1.5). Even though there is obviously less distance to travel from the second point, when VMG is used to estimate the distance, it is illogically shown to take substantially longer than from the starting position at Point 1.

incorrect to attempt to project ETA in tacking sailboats using VMG (See Figure 2).

When you calculate how long it takes to go somewhere, there is an assumption that the speed and distance measures are with interval scales (i.e., all of the units are equally-spaced). VMG is not like this. It is therefore incorrect to use it in multiplication to calculate arrival time.

The systematic errors are greater when you do long tacks instead of many short tacks. Another way to show that Velocity Made Good leads to erroneous projections of ETA is therefore to compare VMG using long versus short tacks. Conceptually, we could assume that it doesn't matter whether you do 2 long tacking legs or ten shorter ones of proportionate length, other than any slight delays while coming around more on short tacks. If the wind stays the same direction, your distances, speeds and arrival times could be identical with two long or ten short tacks. However, Velocity Made Good fails this test as well. It would give you a much lower speed towards the destination on the two long tacks, leading to the erroneous conclusion that it is best to keep making short tacks.

Conclusion

The GPS satellite network was initially developed for military applications. The functions have been fairly standardized across manufacturers. However, modern military forces tend to use power boats a lot more than tacking sailboats these days. Perhaps that is how Velocity Made Good ended up having a prominent role in most GPS interfaces, even though it appears to have very limited value for sailboats and windsurfers.

There is not much awareness that VMG spuriously decreases the longer you remain on a tack. The potential for errors and false conclusions may therefore outweigh the benefits. If the GPS manufacturers are aware of this, it would explain why they make ETA go blank when tacking. These are serious issues for sailors.

VMG seems to be commonly used for calculating Estimated Time of Arrival (ETA) in marine GPS units. However, this causes problems for sailboats. As a measure of velocity, VMG changes depending on how long you are on a tack, which gives it very questionable value. As seen in Figure 2, it also does not make correct or even logical projections of arrival time. For

tacking sailboats, it is not a valid measure of velocity and should not be used to project arrival time. Although manufacturers have provided little explanation, this seems to be why ETA goes blank when tacking.

"Oh yes" says the racing tactician or manufacturer: "everyone" knows that sailors should not use Velocity Made Good as a measure of velocity. Perhaps user guides should state the intended uses more prominently. VMG is okay for power boaters weaving their way home on a direct route, but sailors have been left out.

For sailors, perhaps the only appropriate use for VMG would be in comparing two alternate tacks. Check VMG on an upwind tack where you have good speed but are farther off the mark. Then before your position changes, check VMG using a different heading where you have less speed closer to the wind but less distance to cover. VMG could be used for this relative comparison in the same spot, although you need to be careful to remember that it is not an accurate measure of velocity. If you see 5 miles per hour as your Velocity Made Good and you have 5 miles to go, it would be a mathematical error to then conclude that you will be there in one hour.

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