Navigation Systems - by Christopher Lewis ("Lew")*

Prepared on December 21, 2011**

This article on the subject of navigation systems was prepared at the request of Sally Lindsay Honey in connection with seminars for the Pacific Cup Offshore Academy. The perspective of this article will be a checklist for preparation for ocean-going navigation as you approach a Hawaii race, however the article should have applicability to most ocean or coastal races. The perspective will also be that of a user of navigational equipment, not a vendor; therefore, the main focus of the article is the practical, not theoretical or sales & marketing. Stated differently, I intend to share the sorts of things I might use if I was invited to navigate on your boat. You will see as we move through the topics that I am particularly concerned about having backups to critical nav systems in the event of failure. The back-ups also shed light on what might be perfectly acceptable lower tech solutions for smaller boats, which thereby increases the reach of this article to a broader audience. Outside the scope of this article is non-navigation systems that are essential for a navigator like memorizing the sailing instructions, gathering emergency phone numbers, preparing time deltas to other boats, optimizing routes, and analyzing weather forecasts from weather models, grib files and routing service providers like Commander's Weather.

Historically, the role of a navigator was to define where you are and where you needed to go. Success in finding the destination wasn't certain; in fact, some important discoveries were the result of navigational error. Much more is expected of the modern day navigator, but the good news is there are great tools to help. Navigators today are obviously expected to be able to find the destination, but also get there in the shortest amount of time based on numerous factors, including but not limited to: weather information (both actual and anticipated), current, your boat's capabilities (which are summarized in your boat's polars), sail selections, safety concerns, draft constraints, crew abilities, and the actions of your competitors. The track decided by a navigator is simply the best firing solution after crunching all these variables. With so many factors to consider, it is no wonder sailors often uncharitably label the navigator as the 'naviguessor', however I believe this term unfairly demeans the labor of your modern navigator (and will always earn a dirty look from me). Each section of this article is meant to highlight parts of the system I use to help figure out those routing instructions, with some tidbits (not a systematic treatment of each topic) that might be useful for a navigator or might serve as a jump-off point for discussion in the seminar itself.

Where am I?

In the current day and age, location is almost synonymous with the GPS- global positioning system. But for the classical navigator (and the modern navigator concerned about the reliability of satellite signals in storms, wet circuit boards, dead batteries, fried computers, and even the more remote possibility that governments may shut down satellite data transmission in times of conflict), we shouldn't overlook the sextant and the black art of determining position based on mathematics and the movement of celestial bodies. Nevertheless, as I prepare for a distance race leaving tomorrow, I'll consider the following to determine my position:

- GPS Sensor(s). What GPS sensor do I have on the boat? Where is it located? Is it feeding data into the navigational computer? If so, through what comm port? Do I need any drivers or firmware to access the settings? Do I have any backup sensors that could also feed data into the computer and how do they connect, if the primary stops working?

- Bring a back-up handheld GPS. GPS units nowadays are so cheap that every navigator should have one in their navigator's toolkit. I also stock a USB GPS receiver that I can plug into a laptop in the event of failure of one of the onboard systems.

- Sextant. For the reasons mentioned above, I'd consider bringing a sextant on an ocean race like the Pac Cup or the Transpac. While celestial navigation may not be required for the Transpac anymore, doing it gives you some serious navigator street cred and serves as great practice so you don't forget how to do the calculations.

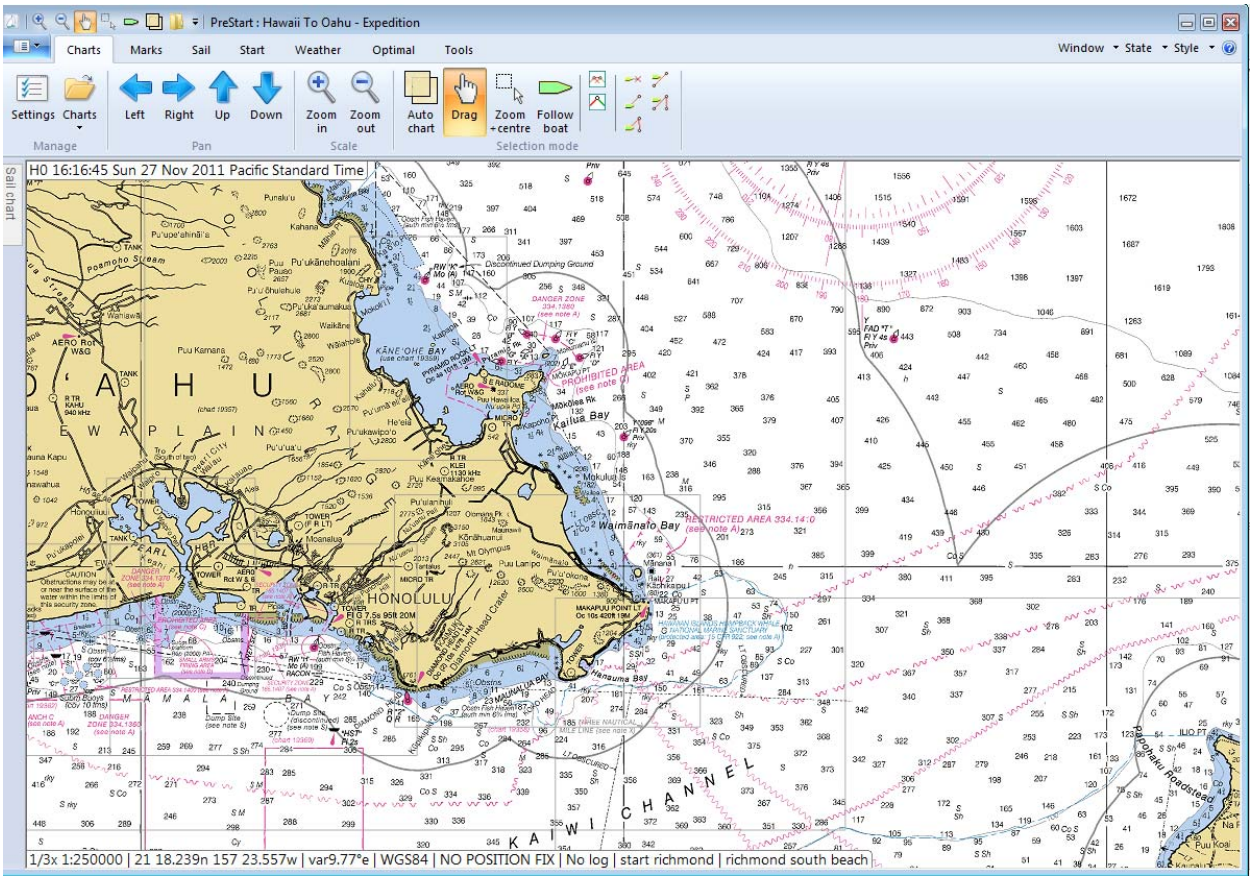
Lew (right) doing sun shots at local noon with Mark Towill of Morning Light and Oakcliff All-American Offshore fame at the helm

Charts

Your lat/long is a valuable piece of data but is obviously so much more useful with the context that a chart can give you.

- Raster charts. A raster chart (RNC-raster navigational chart) is a direct copy or scan of an existing paper chart, so it is, in effect, an electronic version of a paper chart. In my navigator's toolkit, I always carry a memory stick with the free (for US waters) NOAA RNC/BSB charts loaded. That way I am sure to have charts no matter what may already reside on the boat I will be racing. Given that they are free online, having these charts should be a given for any seasoned navigator (and should be updated periodically).

- Vector charts. A vector chart (ENC- electronic navigational chart) is a chart that is computer generated with layers of intelligence, making it more than just a simple raster chart. Aside from the obvious chart functionality, vector charts such as CMAPs are useful because you can, for example, query a buoy for its flashing sequence.



A screenshot of Expedition with a raster chart loaded.

- Paper charts. In the digital world, it is easy to overlook the importance of having paper charts onboard. Even with fancy electronic displays being available, paper charts are useful in giving crew briefings and logging positions. Perhaps it is due to the RYA Yachtmaster course I took which stresses old school navigation fundamentals, but I probably appreciate charts and chart plotting equipment more than most.

- GPS charts. Even the best-equipped boats have equipment failures as we learned on Soozal in the Montego Bay Race/Pineapple Cup (which incidentally has the coolest race instruction ever—"leave Cuba to Starboard") when our alternator gave up the ghost and we sailed for days without consuming any power, except illuminating our running lights. Fortunately, I had packed a Garmin handheld, spare batteries and bought the GPS BlueWater chart chip, so we were able to navigate the reef-laden Caribbean on 2-inch screen and still do race-roundings of the islands to avoid throwing away any distance. Without that GPS and the paper charts, we would have been hard-pressed to get back to port safely, much less be in the hunt for a trophy (we ended up winning IRC B due to the incredible talent and efforts of a phenomenal crew in a big wind race that I will never forget).

- Pilot books. Pilot books for me are useful sources of 'local knowledge' for races courses that I am not familiar. As they tend to be hefty in size, I leave them on the dock, but I summarize the information or scan the relevant sections to my memory stick prior to the race.

Comms

Internet bandwidth on land is lightning fast and cheap. Bandwidth on a boat is precious ("It may be slow but it's also expensive"). Nevertheless, having reliable communications is critical to a modern navigator's duty to optimize routes. Without data capabilities yielding weather information, it is like racing blind and just rolling the dice. As a result, one of the very first things I check out prior to a race is successfully sending and receiving information on whatever the comm platform may be.

- Cellular. This category may include USB modems, PCMCIA modems and even cell phones with data connections that are tethered to a PC. For races that do not take you too far offshore, it is great to use one of these sources for high speed downloads. Their range limits their usefulness for ocean races, but they have their advantages prior to racing or for legs that might come in proximity to cell phone towers.

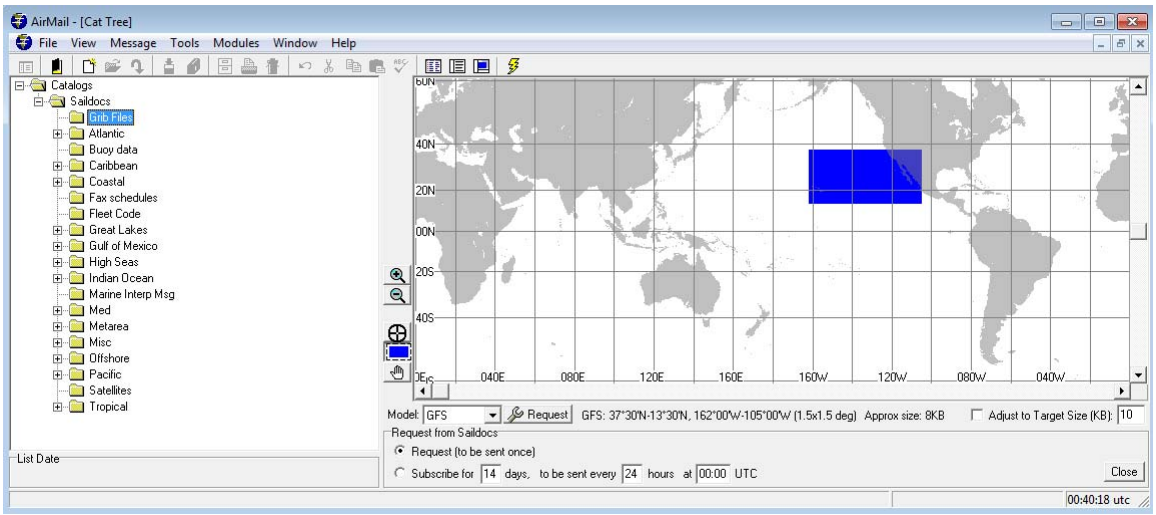
- Satellite communications include Iridium or Fleet broadband. Both provide worldwide access to internet connectivity (with the latter being significantly faster). While at the docks, I will do a quick connection to double-check connectivity and copy down the settings to be sure I have them in the event they somehow get wiped.

- SSB/HF Radio- While the data speeds are a fraction of other means, the SSB provides a reliable and reassuring means to communicate with the outside world. Even after years of using this equipment, it still puts a smile on my face when it connects.

Download GRIB files

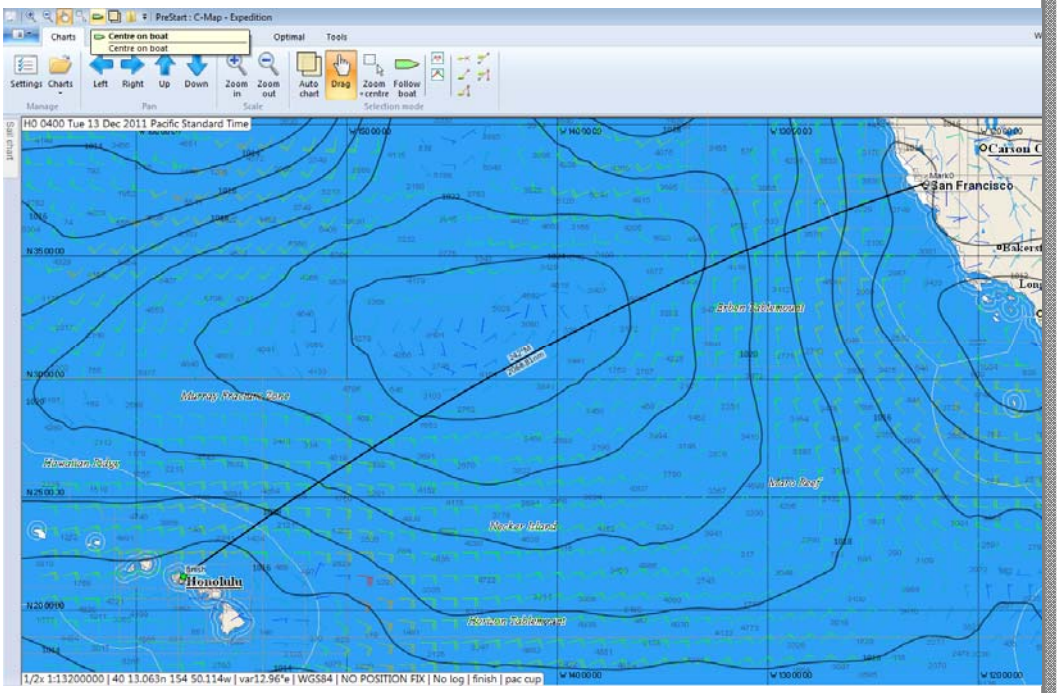
GRIB (GRIdded Binary) files are electronic weather data files using the extension .grb. Weather models, grib file viewing and analysis are beyond the focus of this article, but I will touch on a couple methods that I check to be sure that I can download grib files.

- Airmail Utility. The first step is to be sure that the owner's SailMail membership is updated. Then I try to download a small grib test file, both over SSB and by internet, using the Airmail Software. http://siriuscyber.net/airmail/



A screenshot of the grib downloading utility in Airmail.

- Expedition natively. In the Saildocs menu from the Weather drop down, you can download a grib file and have it directly load into Expedition. I do not typically use the email function in Expedition, but will, if need be.



An Expedition screenshot with a grib file loaded along with the Pac Cup rhumbline.

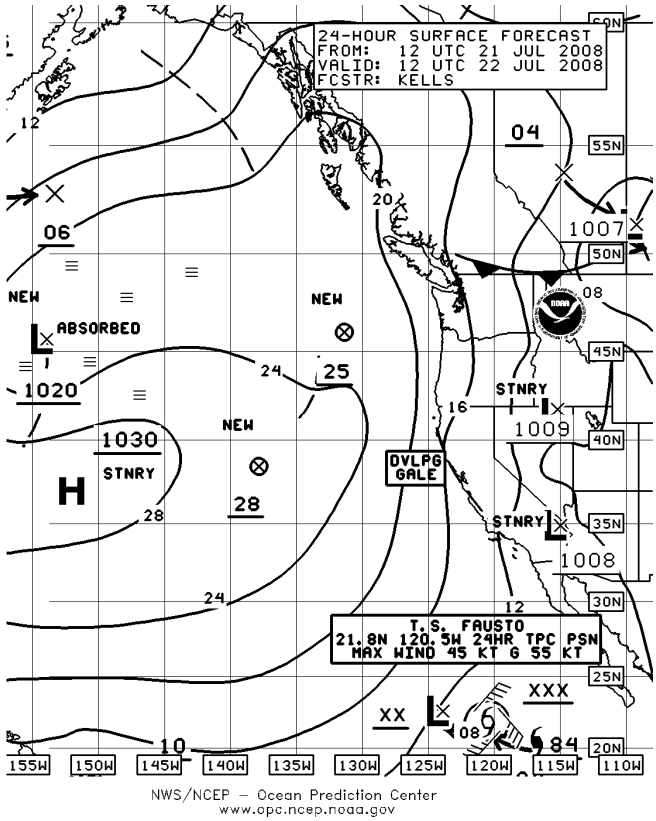
- U-grib. I keep the Ugrib install file on my memory stick, just in case I have some issues with the prior two methods (but that has never happened).

Download Weather Forecast Charts

By weather forecast charts, I mean the ones like you might find at: http://www.nws.noaa.gov/om/marine/nepacificbrief.shtml. These weather charts could not be more useful as they add a layer of human intelligence (which is generally considerable, given the years of experience of the forecaster) applied to the output of the computer models' data. Given the teachings of Lee Chesneau, I would feel almost naked at sea without access to the surface and 500mb charts.

- Get fax. One way to get these charts is through the "Get fax" component of the Airmail package. Given the number of charts available, I like to know ahead of time the exact names of the files, so I do not waste any time or bandwidth at sea.

- List of ftp links. Another means that I use more frequently these days is to prepare a list



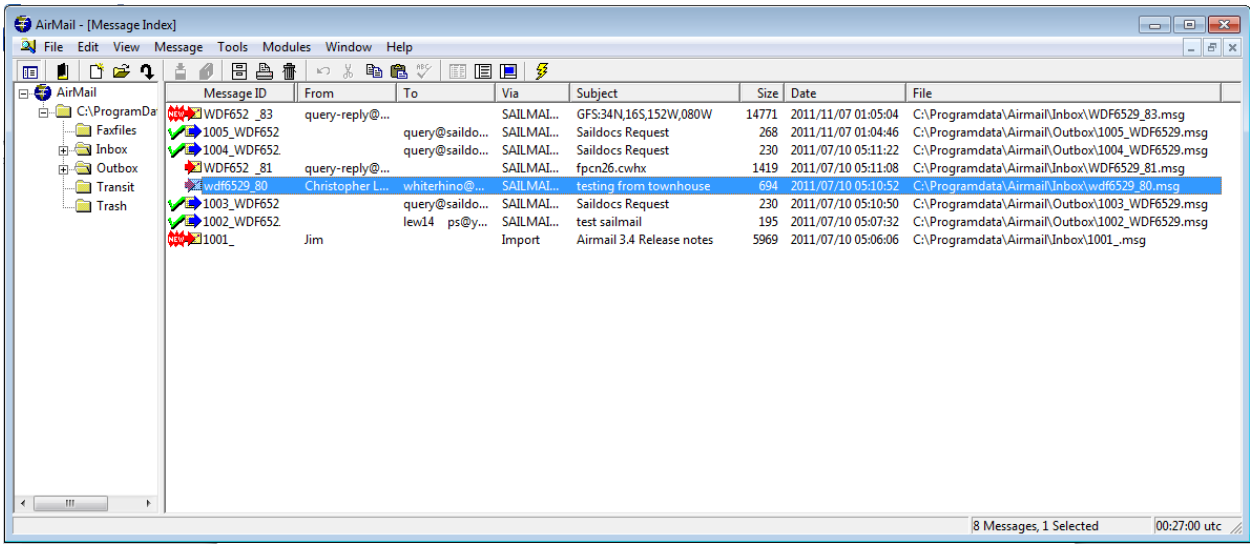
A sample 24 surface forecast from the 2008 Pacific Cup

ftp locations that I plan to access during the race. That way, as soon as I have internet connectivity, I can just right-click and download the target file.

Email

In terms of race performance, email does not add a whole lot for me. While I think it is handy to be able to send position reports to the race committee via email; there are obvious and non-obvious uses for email during a race, such as sending and receiving news from friends and family, getting stock quote information (I have gotten this request more than once), or responding to critical issues at work. That said, offshore sailing provides a refreshing break from the modern reality of checking email constantly.

- Sailmail. I prefer to use Sailmail as it has significant advantages to the bandwidth constrained, plus has seamless integration for getting weather gribs and the weatherfaxes.



- Outlook or Thunderbird are other programs to serve up email, which are more than adequate, but you run the risk that a single large attachment can render it useless for the rest of the race, if the queue gets clogged by a large file that needs to download first over the limited bandwidth. As a result, I caution all recipients of the boat's email address (which is limited to a small group) that email should only contain short messages of text, free of attachments (especially photos), email signatures, or race advice (outside assistance). Good email: "I miss you lots, have a mai-tai in Hawaii for me when you get there. Love, Lady Gaga." Bad email: "Look at the attached satellite photo (large file) that shows the Pacific High coming your way fast. You had better gybe or you'll be sorry! Regards, Armchair Navigator."

Sensors and Processors

- Types and kinds. Another great pre-race prep item is to figure out which instrument systems your boat may have, whether it is, for example, B&G, Ockam, Tacktick, Raymarine, or Nexus. Within each vendor family, you need to find out which sensors you have at your disposal such as BSP, AIS, compass, depth, wind and, perhaps, a clinometer. It is also good to know what sort of processor the system has as you make your inventory of the boat's equipment. I will download the manuals of any instrument package and keep them again on the memory stick because unless you do calibrations for a living, it is not easy to remember every step of the

necessary gymnastics to navigate the non-intuitive instrument menus. Aside from being able to search more quickly, you also cannot justify the weight of bringing the voluminous manual stacks along.

- Instrument installations. It is also important to make a quick check to be sure the sensors are mounted securely to the boat. I've had GPS sensors disappear as people get the boat race ready or BSP sensors that weren't fit snugly in their seat and then subsequently wiggled around.

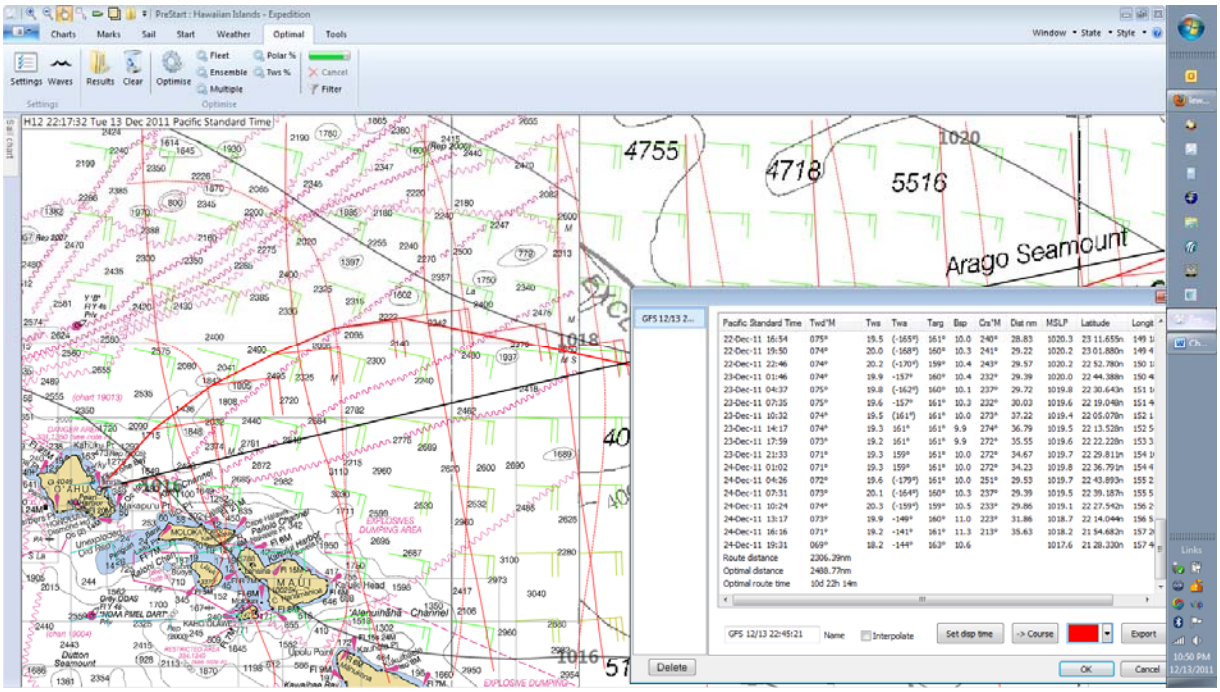
- Calibration. In my experience, there is nothing that can dampen the enthusiasm of even the keenest sailor more than making monotonous trips back and forth for boat speed calibration runs. Yet, there is nothing more fundamental to getting good data than have a rock solid BSP calibration. In general, getting good data for any instrument is as simple as strictly following the calibration procedures in the instrument's manual. Nevertheless, it's also possible to do a quick BSP calibration (or check of the calibration) with a stripchart application, which enables you to quickly average data segments to compare your BSP to your SOG in reciprocal directions. This shortcut works best if you can eliminate some variables that might affect your numbers, such as finding a place to make constant, reasonable runs under power with little leeway or side current, so the main current vector is fore and aft. Calibrating a B&G compass, for instance, is a whole lot more fun and painless as you get the immediate gratification of doing a quick spin and then seeing a 'Pass' on the display. Beyond your basic calibration of tack-to-tack apparent wind angles, getting your wind calibration dialed requires more experience and a keen analytical eye to spot those pesky TWD shifts and TWS inconsistencies. Over time, it has become second nature to check periodically the wind data before and after tacks or gybes and turning upwind or downwind, whenever conditions permit. Time spent calibrating is time well spent as you take the performance of your boat to the next level. The opposite of the above rule is also true: there is nothing that is more frustrating in a long race than trying to process incorrect data based on poor instrument calibration (which cannot be done during a race, but could have been done beforehand). If you have a good fundamental instrument calibration, you can refine the calculations during a race, but if your basic calibrations are off, you are building house on a shaky foundation.

- How data gets into the computer. I may be a bit over the top on this one, but I like to take screenshots of the set-up of key applications when it is working, so that I can put it back to the way it was, if something stops working. It is a special brand of torture to try to figure out the correct baud settings, dial up numbers and com ports in the middle of a race.

Computer/Routing Software/Polars

At first blush, I can appreciate that this may seem like an odd cluster of topics, but I see them as inter-related. Without accurate polars, routing software is not effective or as effective as it might otherwise be. And without a computer, you cannot run routing software. Taking together, having these assets enable you to optimize routes, which as I mentioned at the outset is the key task of the modern navigator. Essentially, route optimization enables the navigator to determine the best course utilizing weather information and the boat's performance characteristics (polars). When I first started optimizing routes with routing software, I can still recall my amazement of the staggering analytical power of being able to design and test potential routes to cross an entire ocean more efficiently based on the unique performance attributes of my boat and forecasted weather information (see also Stan's twin *Sailing World* articles on Polars/Targets and VMG/VMC as well as the *Ockam U Seminar Manual*). Back to reality, it's a great feeling when I'm able to run a realistic sample route prior to a race to start formulating a pre-race strategy. Another important rule that I try not to lose sight of is

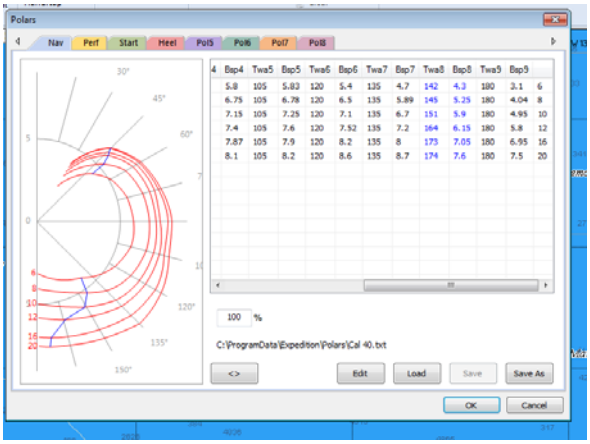
that it is the job of the navigator to apply ***judgment*** to the computer outputs. I use the route optimization as a tool to make decisions, rather than letting it make decisions for me. I approach each computer-generated route with skepticism until I understand the underlying rationale and/or weather data embedded in the optimized track that might, for example, fearlessly and dispassionately suggest a logical, but potentially big risk/big reward strategy of banging a corner of the racecourse from hundreds of miles out (which often happens when you run routes to Hawaii).



An example of route optmization with the results displayed in both a table and chart format. This chart includes the rhumbline (black), optomized track (red) with the wind barbs along the track as well as isochrones, reverse isochrones and weather grib data (green).

- Routing software. Doing yacht races are expensive, so unless you are on a boat with the unlimited checkbook (which are few and far between) I tend to think about the marginal performance improvements per dollar spent. While obviously sails and rigging are all important, I think getting performance software is one of the best performance investments you can make. My personal preference is Expedition, but there are other packages that may suit a boat's objectives like Deckman. The simple message is try to get something and know how to use it before you leave the dock, because you can bet that your competitors will likely have some sort of package themselves. It is also important to note that performance software is not only useful in distance races, but is also very effective in short course racing, though different functionality within the program is used. Again, another happy navigator moment is when I fire up Expedition for the first time and see the boat pop onto the screen (we are getting Lat/Long, COG and SOG) and then the number boxes start populating with wind information (the boats sensor system is successfully sending data to the performance computer).

- Polars. Accurate polars are to me like a holy grail of sailing. Imagine having perfect information about your boat's performance in any wind range at any angle, letting you optimize for any condition you face or will expect to face. If you don't have polars, you should be able to acquire them from any number of sources such as your boat's designers, sail lofts, US Sailing, experienced navigators, and even Expedition has a few sample polars pre-loaded in the application. Like a fine wine, polars do not give up their secrets easily. So as a navigator, you need to assess the quality of the boat's polars for the conditions anticipated for your race. Building on excellent instrument calibration, it takes work in the form of data analysis and number-crunching to understand and refine the polars for your boat. While you should generally resist temptation to massage your polars without detailed analysis, you should consider tweaking your navigational polars to optimize for your racing conditions such as for the sea state or for offshore racing considerations (example: you should never pinch offshore or you might consider the skill of your helmspeople to drive in ocean swell or in light wind).



A screenshot of a polar table and chart in Expedition.

Computer Routing around the Pacific High by Stan Honey

Computer routes suggest courses that are too close to highs when sailing around them downwind, but it isn't due to any bugs or defects in the polars, software, or grib files. Of course, there is a numerical incentive to go close to the High because it is a shorter course, and the routing algorithms assume that the wind is perfectly steady and the helmspeople are perfect, so the computer model takes you right to the edge. In the real world, however, there are light spots, the kite collapses occasionally, and helmspeople lose concentration, and in every event, you have to sail higher briefly to regain speed. And of course whenever you sail higher the wind gets lighter, which causes you to have to sail higher still, and the boat spins out up into the High.

It is like asking a computer to tell you the best path to walk around the Grand Canyon. The computer will correctly tell you to walk exactly on the edge. Of course, we know that that would be too perilous because just one misstep would cause us to fall in, so instead we walk along a few feet away.

Similarly, when rounding the High downwind, use the computer route to assess the closest edge of any sensible course, but instead sail somewhat farther away. The tricky part is evaluating the "somewhat". If the High is very well formed, stable, moving North, or growing, and if you have terrific helmspeople, you can come pretty close to the route (30 nm). If the high is wobbly, dicey, unsupported by an upper level ridge, weakening, or moving South, then it is dangerous and you need to give it a wider margin. It nearly never makes sense to sail North of the computer route.

- Computer. Figuring out the computer's specs is a prime example of what can be done on land before a race. It is important to know, for instance, the operating system, what software is loaded and its versions. There always seem to be drivers that need to be downloaded as well as missing executable applications, which are all good candidates to pre-load on your thumb drive. Don't forget to disable any auto-update functions for software packages that

may cause you to unintentionally chew up bandwidth offshore.

Exporting Data to Deck

It is all well and good to have all the most relevant information at your fingertips down below in the nav station, but eventually you as a navigator will have to boil it all down and tell the skipper and/or crew what to do.

- Exporting data to deck displays. Some instrument systems have the ability to let the computer talk to deck displays, allowing you to send any number of data feeds up on deck. For a navigator, it provides a way of communicating to your teammates without having to say a word. On really long races, sometimes it is nice just to have a little display showing the bearing and distance to the bar, that way you do not have each crewmember asking you several times a day that same critical information. Deck display exporting capability enables you to present useful performance data like two displays next to each other showing boat speed vs. target boat speed or true wind angle vs. target true wind angle, or even a single display with a course to steer or percentage of perfection on a reach (BSP/polar BSP). By measuring the boat's actual performance against theoretically perfect performance data, the drivers and trimmers will receive immediate feedback as to what is working and what needs to be improved. This concept brings together the importance of all the topics presented earlier because bad data in (polars and calibration) means bad data out (performance evaluation and route generation).

- Briefings with watch captains/skipper. With or without data being piped up on deck, there is no substitute for effective communication with the leadership of the boat. Things change and if you expect to win, your drivers and trimmers need to be able to react more quickly to the new race conditions than your competitors. Imagine a scenario where, before getting some well-deserved rest, you give the crew instructions to keep driving at a given target true wind angle in 16 kts of wind (it seemed like a good idea given the importance of polars), which has you doing a reasonable 270 COG on the fast track towards Hawaii. However, not 10 minutes after you slip off into dreams of fast internet, dry beds, podiums, Philly cheesesteaks and mai-tais, the wind clocks 40 degrees with the wind speed remaining the same. You had been plotting a careful course to sail the minimum distance to Hawaii, but wanted to get no further North to prevent spinning out into the lightness of the High. You wake to find that for the last hour (or longer), you averaged a 310 COG pointing somewhere towards Siberia (your course over ground veered with the windshift since your TWA was fixed). After waking up to that hypothetical nightmare, you will never forget to let your fellow decision makers in on the game plan because you have to assume that you can't be watching your course all the time.

- Tablets. Using a tablet computer is a great way to untether the navigator from the computer below. A tablet display permits the navigator to access all the information in the nav station, but on deck where you might combine the computer info with real world observations such as feeling the wind on your neck and analyzing the visible clouds and sea state. I can recall doing a Hobart when I was young where the navigator was like a groundhog that would pop up from his hole every so often in his thermal pajamas, give some orders, then vanish back to his warm nest while the deckhands banging through the Bass Strait were wet, cold and grumpy.

  As result, I try to avoid locking myself away in the nav station for many reasons, not the least of which is you get a better sense of what decisions to make when you have the experience of trying to execute them yourself by driving or trimming. I am sure everyone can remember a navigator who gave a course to steer instruction that seemed more like a wish than reality given what was possible to drive to. That said, you do not need a high

tech tablet to avoid staying below deck too long, but it is extremely helpful if the boat has one or you can borrow one for a long race.

Physical Items

- Watch. As old school as it seems, the watch is essential. I prefer the Suunto Yachtsman, though obviously there are plenty of other alternatives. It is handy for the start, keeping elapsed time of the race, making log entries, and waking up at zero dark thirty. I also use the watch's dual time function so that I can know what time it is at Zulu time for the weather model runs.

- Barometer. The barometer is another essential bit of kit. It is useful for tracking lows as well as riding an isobar in the 'slot car' portion of a Hawaii race (see Stan Honey's Hawaii race articles for the reference). The Suunto Yachtman also has a barometric logging function that is useful to see trends. Another use for the barometer that sailors might not realize is to validate and calibrate the weather model information that we receive at sea. For example, if you are 6mb off the model information, either your barometer is off or your weather forecast is.

- Handbearing compass. Most tacticians would not leave home without it for a buoy race, but it is an often-overlooked item in a distance race. Offshore, the obvious application for a compass is to determine gains and losses against other visible boats. However, I have also found it essential for squall tracking in Hawaii races. So when Stan says, "to go to school on the squalls", I use a hand bearing compass to do my homework by observing and recording the squall's bearing and size, as well as time-based deltas of both to determine a squall's path. This enables you to get in front of a squall for more breeze like catching a wave on a beach. Knowing the path of the squall can also help you avoid the light winds trailing behind a squall.

I hope that you have found this article as a helpful reference and/or checklist for navigation systems. As you can see, the prep time prior to the start of the races is critical for me as a navigator as I try to do things outlined above while on dry land when you have fast internet and can ask for help without it being considered outside assistance (RRS 41). As a result, I tend to be pretty anti-social before races and have even been known to wear earphones at the nav station just to avoid the distraction that my fun crewmates can present. In closing, I can imagine my fellow crewmates from past races saying, "Now I finally know some of the things he was doing before the race with those headphones on."

Although an amateur sailor with a full-time day job, Christopher Lewis ("Lew") has sailed for some very competitive yacht programs such as Easom Rigging's Eight Ball (both the Moore 24 and the Mumm 30), Soozal and Pyewacket. His experience includes buoy races, Hawaii and Mexico races, Newport Bermuda, Sydney Hobart as well as races throughout Asia. Lew has a Laser EPS and a Cal 37, the latter serving as a floating apartment in San Francisco for spending quality time with his family and friends.

*Thanks for the contributions of Selig Berman of YachtSoft, Sally Lindsay Honey, and Stan Honey.

** I take care to define the date as navigation systems are intimately tied to technological innovation. As a result, the article is based on technology that exists if we were leaving tomorrow. Obviously, professional race boats might have even more navigation systems, which you'd want to be sure to test before a race, but the intention of this article is to serve as a useful baseline, i.e. not intended to be bleeding edge technology, but not pre-historic either. No doubt, there will be continued innovation that will make this article seem tremendously outdated in 10 years.