CHAPTER 26

BATHYMETRIC NAVIGATION

BASIC TECHNIQUES OF BATHYMETRIC NAVIGATION

2600. Introduction

Until the arrival of this age of electronic technology, mariners relied solely on celestial navigation, paper charts and mechanical soundings techniques to navigate the world's oceans, Now, however, satellite technology, GNSS, and electronic positioning systems are capable of achieving sub-meter positioning accuracy, and vessels can even navigate using automated means alone. Satellite navigation has become so reliable that some maritime academic institutions have removed celestial navigation from their curriculum. Hydrographic offices, too, put the bulk of their efforts on producing electronic navigational charts in response to increasing industry demand for digital products and decreasing need for paper charts.

However, all things electronic are subject to the potential for failure, and as technology advances it is possible to become over-reliant on a single set of tools. As the maritime sector gradually acknowledges this vulnerability, there is renewed interest in traditional navigation techniques. For example, bathymetric navigation, which utilizes charted seafloor features and contours to help determine the position of a vessel, is once again being actively used in combination with celestial navigation or dead reckoning to provide a position solution in the absence of satellite navigation.

2601. Bathymetry and Bathymetric Navigation

Bathymetry is the science of mapping seafloor relief. Accurate bathymetric surveys help hydrographers identify submerged hazards to navigation, and allow oceanographers and geologists to better understand seafloor morphology and its impact on the ocean environment.

The principle behind bathymetric navigation is simple. When a mariner knows a vessel's last position with reasonable confidence, and has nautical charts that depict soundings, seafloor features and depth curves, then the mariner can use those charted bathymetric features to refine their assumed position.

For example, if a mariner were to be navigating in the vicinity of a charted seamount, and there exists a measure of uncertainty regarding the accuracy of their positioning fix, the mariner can validate the vessel's position by comparing echo sounder readings with the assumed position while sailing over the submerged seamount.

The usefulness of this technique is dependent up on several factors: the accuracy of the chart, the reliability of the last position fix, and the capabilities of the vessel's echo sounder.

The National Oceanographic and Atmospheric Administration (NOAA) produces a series of bathymetric maps of the waters adjacent to portions of the coast of the United States. These maps extend seaward somewhat beyond the 100-fathom curve and show the contour of the bottom in considerable detail. Such maps can be of great assistance in fixing position by means of the depth finder. The maps are available online and can be accessed via the link provided in Figure 2601.

Figure 2601. NOAA - U.S. Bathymetric Maps
https://www.ngdc.noaa.gov/mgg/bathymetry/maps/nos_intro.html

2602. Nautical Charts

Nautical charts are compiled from a combination of bathymetric surveys, soundings collected using a variety of historical techniques, and depths reported by mariners. Although it may be tempting to assume that where there are soundings on a chart, the area has been thoroughly surveyed, this can be a dangerous presumption. It is not an over-generalization to say that most of the world's oceans are still unsurveyed.

The ocean is vast, and although technology is always improving, modern hydrographic surveys are still expensive and time-consuming. In many areas, charted soundings are compiled from pre-1900 lead line surveys, or from 20th century singlebeam echo sounder surveys (see chapter on Hydrography for more information about survey techniques). These survey methods do not provide full sea floor coverage, and could miss significant seafloor features.

In addition, much of the depth information in nautical charts was collected before modern satellite positioning techniques were available. This introduces a degree of uncertainty in the location of some charted depths. Mariners should always consult the chart's source diagram to determine the type and age of data that was used to compile soundings for any specific region of the chart, and always use the best-scale, most current product available for bathymetric navigation.

2603. Positioning

When vessels navigate using GNSS, mariners can usually be confident in the accuracy of their position fix. There may be times when the quality of the satellite signal degrades due to poor geometry overhead, or steep terrain that blocks signals or causes multipath (such as in narrow fjords), but generally, satellite navigation is reliable.

If, however, a navigator is unable to use satellite positioning systems, they will need to rely on other methods, such as celestial navigation or dead reckoning (or a combination of the two). With accurate celestial navigation measurements, obtained through practice and skill, mariners can determine their position with a reasonable degree of accuracy (see Part 3 on Celestial Navigation for more information).

When persistent inclement weather or overcast skies prevent mariners from taking star sights or sun fixes, then mariners must resort to dead reckoning. Dead reckoning measures the amount of time elapsed since the last known position fix, the speed of the vessel, its ordered course, and known set and drift to derive an estimate of the vessel's location. The reliability of dead reckoning degrades with time, as the compilation of slight errors compound.

Because there is almost always some uncertainty in position fixes when using celestial navigation and dead reckoning, mariners find it useful to better determine their location using bathymetric navigation.

2604. Echo Sounders

Most modern vessels, from small pleasure boats to large cargo ships, have some type of electronic echo sounder mounted on the keel. These echo sounders measure the time it takes for a pulse of sound to travel to the seafloor and return to the transducer. This measurement of time is then electronically translated into a depth measurement, and the navigator of the vessel uses the depth measurement, in tandem with a nautical chart, to determine a safe course.

Echo sounders vary widely in design and capability. Many models collect depth information about only a narrow cone of water beneath the vessel. These may be referred to as singlebeam SONAR, fathometers, or depth finders. Some higher-end models emit many beams of sound, in a wide swath below, or in front of the vessel. These designs are called multibeam systems, and are capable of generating a very high-resolution three-dimensional SONAR image of the seafloor or approaching obstacles (see chapter on Hydrography for more information about echo sounder designs).

All echo sounders are limited to a certain depth operating range, which is constrained by the power and frequency of the system. In general, shallow-water echo sounders will be higher-frequency, and require less power. Deep-water echo sounders will be lower-frequency, and require more power. Echo sounders are capable of detecting smaller features in shallow water, and their resolution degrades with depth pulses.

Before attempting bathymetric navigation, mariners should determine what kind of echo sounder they have on board. This will help them identify the capabilities and limitations of their system. For instance, with a singlebeam echo sounder, the mariner would be able to compare charted soundings to depth measurements, and follow patterns in depth trends that correspond to charted contours. With a multibeam echo sounder, mariners might be able to generate very high-resolution SONAR maps of the seafloor. While this could help the mariner identify charted features, it is also possible to collect higher-resolution data than depicted on the chart!

Regardless the type of echo sounder used, it is likely that, at some point, vessels will collect depth information in transit where there is no charted data. This information can be valuable for oceanographic studies, hydrographic purposes, and the greater public good. For those who will donate their data, the International Hydrographic Organization (IHO) supports a crowdsourced bathymetry initiative that encourages mariners to connect data loggers to their echo sounders, and submit the collected information to a public database. For more information, See the link provided in Figure 2604 or visit www.iho.int.

It is also possible to collect depth information without an echo sounder in shallow water, using a lead line or sounding pole. These techniques are not widely used today, as they are time-intensive, and require stopping the vessel and manually deploying a weighted line or long pole over the side. However, they are reliable methods of obtaining depth information, and in theory can be used to compare charted depths with measured soundings.

Figure 2604. IHO World Bathymetry
https://www.iho.int/srv1/index.php?option=com_content&view=article&id=300&Itemid=744&lang=en

2605. Sound Velocity

Mariners should be aware that the depth measurements collected by echo sounders will vary based on the temperature, salinity, and depth of the local water column. Each of these factors has an impact on the speed and path of sound waves through water. In general, sound travels faster through warm water, saltier water, and deeper (denser) water.

Because echo sounders generate a depth measurement based on the two-way travel time of a sonar beam, differences in water column composition can generate variations in depth measurements. For example, if a vessel travels through a coastal area where a freshwater river runs into the sea, the speed of sound will slow, and the depth measurement may be slightly incorrect.

Some echo sounders have a surface sound velocimeter installed on the hull to at least partially correct for these local water column variations, others do not. Before attempting bathymetric navigation, one should determine whether or not the echo sounder is equipped with integrated sound velocity corrections.

2606. Other Considerations

Sound waves from an echo sounder will reflect off of anything in the water column, and may even penetrate the surface layer of soft or muddy bottom sediment, and reflect off of the underlying bedrock. Fish, bubbles (from marine life or another ship's wake), dense layers of plankton or marine life, vegetation, variations in salinity, and marine mammals can all cause 'false bottom' readings, or obscure the true bottom. Mariners should be aware of these exceptions when using fathometers to identify seafloor features.

BATHYMETRIC NAVIGATION USING FEATURE RECOGNITION

2607. The Basics

Once the mariner has obtained an initial position fix, determined a rough assessment of the age and accuracy of the information used to compile their chart, and identified the type of echo sounder that is mounted in their vessel, they are ready to use bathymetric information to verify their position.

For the purposes of this chapter, we will assume that the mariner is using hardcopy charts and non-satellite positioning methods, and is navigating out of sight of land. Note that if the mariner is within sight of land, it may be easier and more accurate to verify position by simply taking bearings on features on shore, rather than by comparing bathymetric features to echo sounder readings.

If the mariner is beyond the sight of land, they should choose a prominent charted seafloor feature or set of features that fall near their estimated position, and are at a depth that permits the vessel to safely transit across it. The features should be unique enough to be readily detectable (such as seamounts, ridges or canyons), but should not be complex or 'clumped' features, as they will be more difficult to distinguish and use for positioning. The feature should have enough relief to be easily distinguishable from the surrounding seafloor. If the seafloor is flat and featureless bathymetric navigation will not work, as all depths will appear relatively uniform.

Ideally, the mariner should select a feature that falls within an area recently surveyed for hydrographic purposes (as indicated on the source diagram); those features are likely to be more accurately and fully represented than features from other sources. For example, if an area was fully surveyed using multibeam sonar, a cartographer knows exactly where the 50m contour is located. If an area was surveyed with isolated lead line soundings, the cartographer has to make an educated guess about where to draw the 50m contour between soundings.

If there are no recent hydrographic surveys in the area, the mariner should simply choose a feature that is prominent, and is not listed as 'reported,' 'position doubtful,' etc. Some features that may be useful for bathymetric navigation are:

- Seamounts (isolated or in small groups)
- Ridges
- Canyons
- Plateaus

Once the mariner has selected the feature or set of features, they should plot a course across the feature (or features), reduce vessel speed so that the echo sounder return provides a clear and easily readable bottom trace, and then transit over the feature, attempting to intersect it in a direction that provides the clearest delineation of its location.

If the mariner is using a ridge or a canyon to verify position, the vessel should cut across the feature in a direction that is perpendicular to its main (long) axis. The echo sounder will provide a clear profile of the sides of the feature, and the positions and depths can then be compared to the contours or depths on the chart.

If the mariner is using a plateau or seamount to verify a position fix, the vessel may need to make one or more passes over the feature, which each line offset at a different angle from the last, to ensure that they have located the feature, and not just clipped the edge. If the area is poorly surveyed, caution should be exercised when doing this, to prevent the vessel from encountering a portion of the seamount that is shoaler than charted.

Whenever possible, it is best to transit more than one feature in a row, as locating multiple features that area aligned at a single known bearing provides the most accurate position verification

2608. Additional Considerations

When using bathymetric features to validate a position fix, it is important to note that the vessel's last known position should be reasonably reliable. If there are gross errors in dead reckoning measurements or celestial navigation calculations, bathymetric positioning will be of little value, as the mariner will be searching in the wrong area to begin with. Bathymetric navigation should be used as a refinement of last known position, not the sole positioning determination method.

In addition, it should be noted that the sonic footprint of some singlebeam echo sounders can make the sides of submerged features appear more rounded than they actually are (Figure 2608). This should be taken into account when comparing charted contours to echo sounder traces.

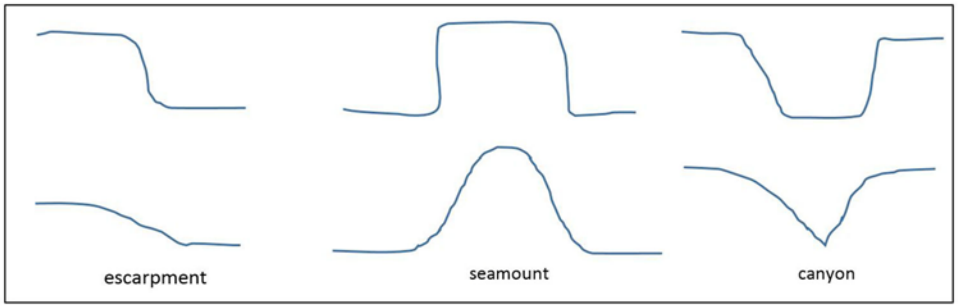

Figure 2608. Bottom features (top row) compared with measured echogram (bottom row).

2609. Other Positioning Methods

Profile-matching. If a vessel is operating in an area where there are no significant features, but the charted contours are varied enough to assist with position identification, a vessel could transit back and forth across the area in a grid pattern, recording the depth profiles with each pass, and then correlate those sequential profiles to the charted contours.

Profile-matching is more time-consuming than the feature recognition method, but if executed properly, and where good comparison contour data is available, this could yield very accurate positioning information. If the vessel has a multibeam echosounder on board, this process would produce a fairly high-resolution map of the seafloor.

Contour Advancement. As with profile-matching, contour advancement does not require that significant features be present, but it is desirable to transit across a gently sloping area with slopes that are greater than one degree, but no more than four or five degrees. The area should also be well-charted, with moderately reliable contours.

To use the contour advancement technique to verify a position fix, a vessel must transit across an area at a constant bearing and speed, in line with the direction of a known slope. When the (singlebeam) echo sounder depth matches a charted contour depth, the navigator knows that the ship is somewhere on that charted depth contour - but precisely where is unknown. This first contour becomes the 'reference' contour, and is traced onto a transparent overlay that will be shifted (or advanced) on the chart as new contour depths are collected.

When the echo sounder indicates that the vessel has reached the next charted contour depth, the navigator moves the reference contour overlay forward to the new estimated position on the chart. The distance that the contour is advanced is determined by measuring the time it took to travel between observed contour soundings, and multiplying that time by the vessel's constant speed.

Advancing the reference contour has the effect of moving every possibility of the ship's starting location on that first contour visually into the vicinity of the next contour (basically, offsetting every point on the first contour by the distance covered, without having to manually draw all of those infinite offset points). If executed accurately, the intersection of the advanced contour (i.e. the first contour, offset by the distance covered) and the next charted contour will note the true location of the ship, provided that there is only one intersection.

Multiple intersections of the reference and charted contours means that there is more than one possible position. The mariner must then continue the contour advancement process to determine which candidate is the true track.

In the Figure 2609, the solid lines are charted contours, and the dashed lines are the advancement of the initial reference contour. The ship's estimated track (which the navigator plots on the overlay, and could have started anywhere on the reference contour) is the dashed line perpendicular to the contours. The time between echo sounder observations of charted contour depths is annotated on each track. The ship's true position is shown on the right; it identifies the areas where the vessel crossed each of the contours, after the advanced contour indicated the points of intersection.

Typical accuracy for contour advancement is approximately one-quarter of the contour spacing of the chart.

Basic Rules of Thumb for Contour Advancing are as follows:

- An accurate bathymetric chart of the region being traversed is required.

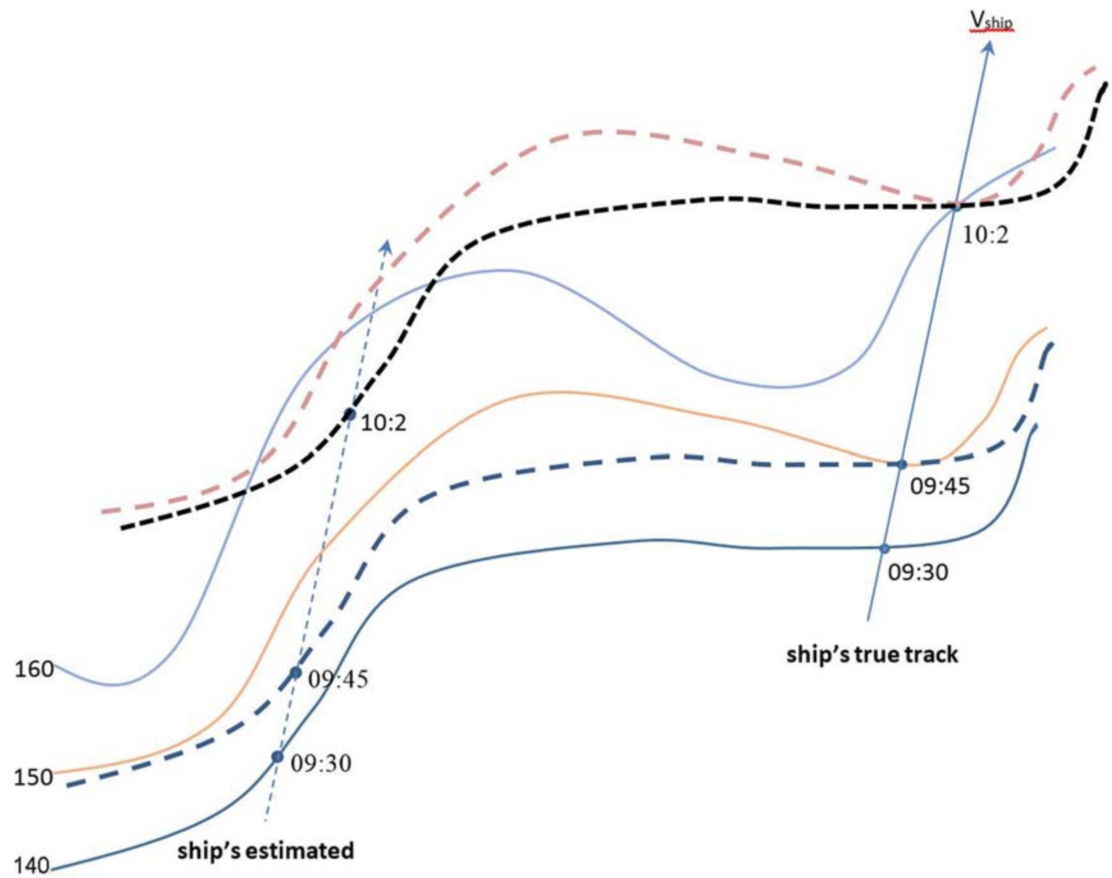

Figure 2609. The technique of contour advancing is illustrated in this figure. The isobaths shown in Figure 4 as solid lines are the contour lines on the chart; all dashed isobaths are results of contour advancement of the chart isobaths. Shown here for convenience is the true ship's position track, which is unknown to the navigator. The time of passage of the charted isobaths is also shown on the true track for convenience, more importantly, they are shown on the ship's estimated position track, which the navigator is plotting on the chart. Initially, the navigator traces the 140 isobath onto the overlay at 9:30 and establishes a reference point anywhere on the traced 140 isobath. Also note that this procedure can be performed after the fact if the times of passage, their charted depth, and the ship's velocity have been recorded for later use. When the next charted isobath, 150, is passed at 9:45, the navigator advances the overlay to the new estimated position. The advanced 140 isobath must intersect the charted 150 isobath at the ship's true location. If this is the only place of intersection of these two isobaths, the fix can be established at this time; the location of the intersection of the two isobath's is the ship's true position at 9:45. But there may be multiple locations of intersection, one of these is hinted at on the far right side of the displayed contours and perhaps one slightly to the left of the ship's estimated position. The advancement can then continue to the next charted isobath, 160, to help resolve the true location. In that case, the advanced 140 and 150 isobaths hint at possibly intersecting again at the far right, but the charted 160 isobath diverges from them there, and the location slightly to the left of the estimated ship's track doesn't show a strong three-way intersection like at the point on the true track at the point labeled 10:20, showing that the point labeled 10:20 on the true track would be the ship's true position at that time. The intersections may form a triangle instead of a point due to errors, the smaller the triangle, the better the confidence in the fix; or perhaps additional contours can be advanced to help resolve the fix if the error triangle is too large. Typical accuracy is on the order of ±100 yards, or about one-quarter of the line spacing of the chart.

- Slopes should be between 1° to 4° (no more than 5°), and they should be varying; use of areas with constant slopes could result in intersections which are along lines, not at points, and so would not reveal precise location.
- Contour advancing is made easier by using the largest scale chart available, assuming the area is not absolutely flat. A given chart may not show any slope for a given area, but the area may show some relief on a larger chart.

2610. Line of Sounding Technique

Recovering a position fix using the line-of-soundings technique is similar to contour advancement, but usually requires collecting more observed depths to obtain an accurate fix. A vessel using a singlebeam echo sounder runs a single straight line over a charted area at a constant bearing and speed, and the sounding values that correspond to charted contours are plotted onto a trackline on a clear chart overlay. The line is then moved across the charted contours, until the plotted soundings match up with the charted contour interval. This provides a position fix. If a vessel is using a multibeam echo sounder, the continuous swath of seafloor data can also be compared to the charted contours, to identify matching patterns with higher fidelity.

In Figure 2610, the red lines represent the singlebeam echo sounder trackline of plotted overlay soundings. The navigator moved this trackline across the charted contours, using the 500m contour as a central reference guide, until they found a match (the trackline in the center of the chart). Like other forms of bathymetric navigation, this method would not work in a very flat area, since the trackline would appear to match the depths in many directions.

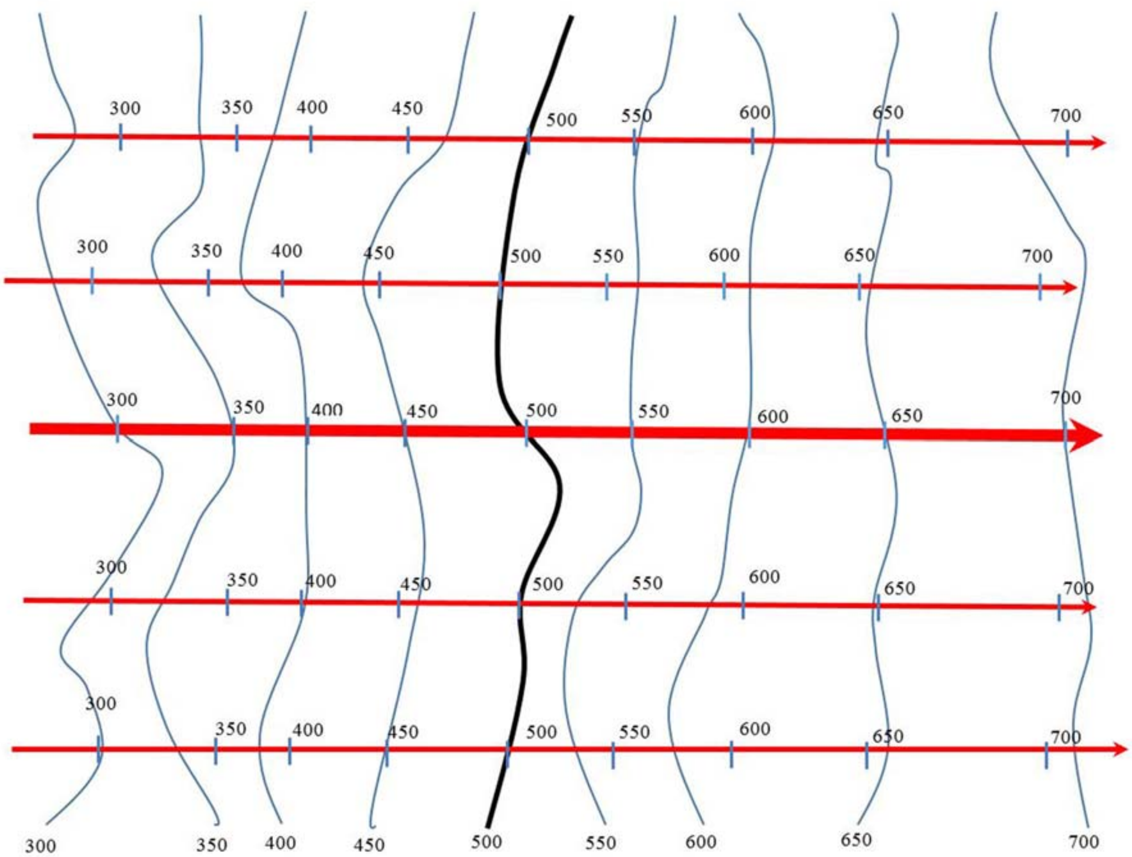

Figure 2610. Line of soundings technique. Image courtesy of Johns Hopkins University - Applied Physics Laboratory.

2611. Side Echo Technique

The side-echo technique is useful for determining position when traversing seamounts. For this method, the vessel must conduct at least two transit lines across the seamount, each of constant bearing and speed, offset from each other at right angles. The depth trend on each line indicates the quadrant location of the shoalest (shallowest) point of the seamount, relative to the intersection of the transit lines.

The navigator should plan the initial transit line so that it approaches the seamount from a distance of at least 20 or 30 nautical miles. In deep water, this distance will help the navigator identify changes in seafloor relief and will help prevent missing the feature (the track should capture at least the base of a large feature, even if the shoalest point is missed). The vessel should maintain a constant course while approaching the seamount. If the vessel is using a singlebeam echosounder, the navigator should plot the depths at regular intervals (e.g. once per minute) while crossing the feature. The minimum depth should be noted and marked on the trackline.

Once the initial transit has crossed the feature, the vessel should run another transit line, exactly perpendicular to the first. The navigator should again plot the depths periodically, and annotate the point of least depth. If a line is then drawn between the shallowest point on each line, the point where they intersect indicates the quadrant of the shallowest point on the seamount. If the vessel is using a multibeam sonar, the overlapping swaths from each line should show a clear depth trend towards one quadrant, and could even capture the shoalest point of the feature.

Once the approximate location of the shallowest point of the seamount is determined, that location can be compared to the charted minimum depth, to provide a position location for the vessel. Additional lines, offset to the first two, could help to more precisely locate the shoalest points. However, it is important to note that the charted minimum depth of the seamount could be wrong; previous surveys or reports may have only crossed over one side of the seamount, instead of directly over the shallowest part, or the horizontal positioning methods used at the time may have been inaccurate, and the seamount's location could be slightly incorrect (see Figure 2611b). Whenever possible, the mariner should try to select a feature that comes from a reliable source, such as a hydrographic survey.

Figure 2611a. Link to NGA's Maritime Safety Office - Contact Information.
https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&pageLabel=msi_contact_info

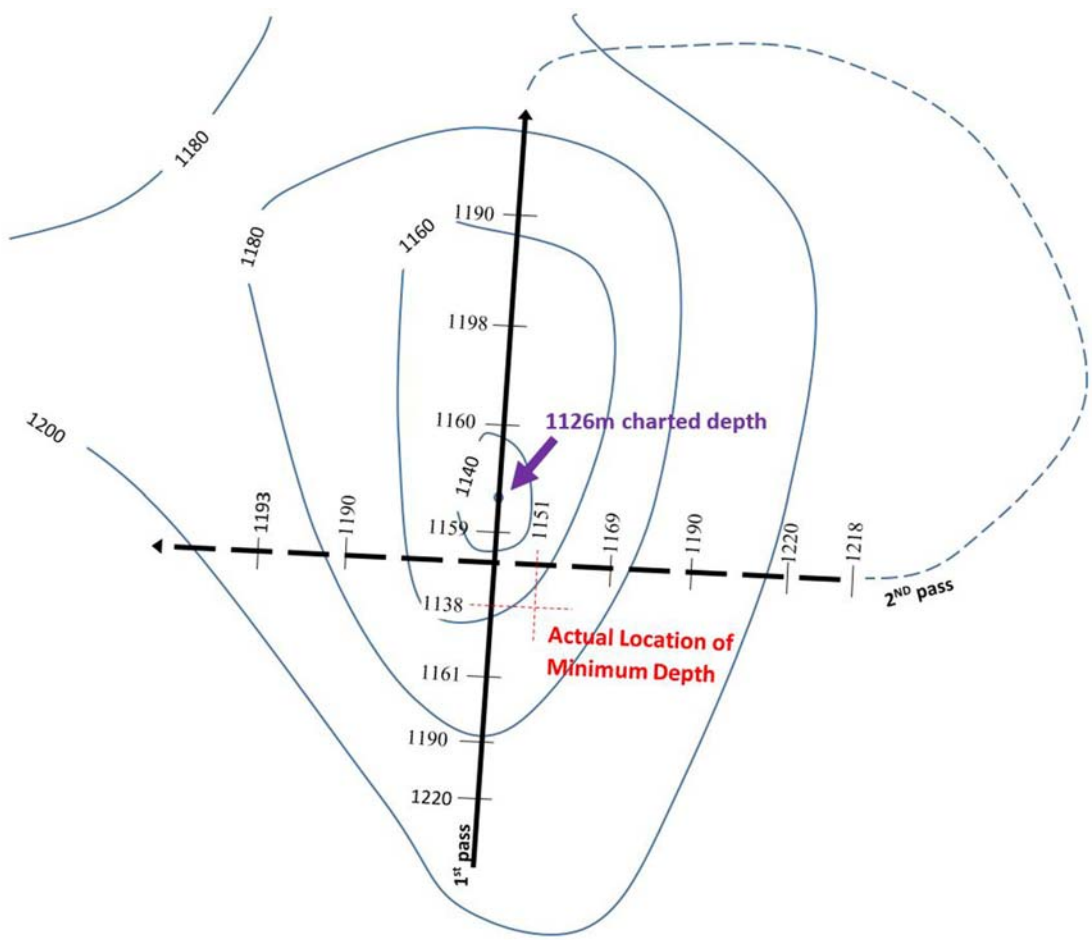

Figure 2611b. Side-echo bathymetric navigation. This image is provided courtesy of Johns Hopkins University- Applied Physics Laboratory.

If a mariner finds that the actual depth of the seamount is shallower than the charted least depth, that information should be reported to NGA's Maritime Safety Office as soon as possible (see link in Figure 2611a), so that the chart can be updated.

2612. Computerized Techniques

Automated programs exist that can incorporate singlebeam or multibeam SONAR data, along with the speed and course of the vessel, and compare that data directly to digital features and chart contours. These programs can provide an approximate position fix without the need to manually overlay and plot soundings.

2613. References

Cohen, P M., (1970). *Bathymetric Navigation and Charting*. U.S. Naval Institute Press, Annapolis, MD. **Sections reprinted with permission.**

Cutler*, T J., (2003). Dutton's Nautical Navigation,* 15th Edition. U.S. Naval Institute Press, Annapolis, MD. **Sections reprinted with permission.**