Traditional Navigation in Pilot Waters. 24 October, 2006

Traditional position-fixing methods have a long history of providing the basis for safe navigation, when used by experienced navigators. In order to use these methods, a navigator must have the equipment, the skills, and the incentive to achieve continuous safe and accurate navigation. This paper will describe the traditional methods of position finding in near-shore waters, their strengths and their weaknesses, which vary depending on the ship's location, instrumentation, the weather conditions, and the skill and work of the navigator and the piloting team. It will address the limitations of these methods as a backup to electronic position-fixing systems.

Traditional navigation in the vicinity of hazards is demanding work. "No other form of navigation requires the continuous alertness needed in piloting. At no other time is navigational experience and judgement so valuable. The ability to work rapidly and to correctly interpret all available information, always keeping 'ahead of the vessel,' may mean the difference between safety and disaster." DMAHTC PUB #9, *Bowditch,* 1984

Methods

Visual lines of position (LOPs) can provide reliable fixes, provided that the ship is near identifiable visible objects. These fixes are one important element in navigation, but navigation entails many other important elements: planning, cross-checking, verification, examining the projected track for hazards, and predicting future locations. The ship should have a gyrocompass, and gyro repeaters with bearing or azimuth circles in appropriate locations to take visual bearings, such as the bridge wings. There must be an up-to-date chart, a chart table, and appropriate plotting instruments. Other instruments essential to traditional navigation include depthfinders, a speed log (or an RPM/speed table), a watch, and binoculars. These are nearly universal aboard ships today. So is radar, which is essential to safe low-visibility navigation.

Advantages

The great advantage in traditional position-fixing lies in the fact that it uses visual signals, landmarks, and to a lesser extent, sound signals. Traditional navigation does not depend on external man-made electronic signals for position fixing, and thus does not suffer from anomalies in, or interference to, long-range electronic signals. Independence and reliability are the great strengths of traditional position-fixing.

Disadvantages

There are many disadvantages to traditional position-fixing methods. The necessary equipment and instruments are commonplace, but the effort to learn traditional methods thoroughly, and the time and effort to keep the ship's position up to date constantly, are huge. If you buy a musical instrument, you only have the potential to produce good music. Think of the time, dedication, and effort to play it well, and you will have an idea as to the training, practice, and work required to find a ship's position at frequent intervals in hazardous waters. In both cases, the instrument costs are small relative to the personnel costs.

Personnel requirements

A ship at sea usually records a satellite-based fix every hour. This interval decreases to fifteen minutes as the ship approaches port. When the ship comes in sight of land and enters a bay, it is necessary to take fixes more frequently. It requires several trained people to plot visual fixes quickly and accurately in pilot waters. This is not merely the author's opinion. *Bowditch*, Chapter 8, Piloting, states in paragraph 814, *Fix Type And Fix Interval*, that a fix interval of three minutes is optimum for a multi-person piloting team, including a navigator, bearing takers, a plotter, a radar operator, in addition to the conning officer. The same reference indicates that the Captain will also be on the bridge. It is not uncommon for the navigator and his team to require around five minutes between fixes. This represents about a mile and a quarter at typical deep draft ship speeds in channels.

High quality visual piloting is possible with fewer people, but is well beyond the capabilities of any one person, even one who is not the deck watch officer. As a personal note, only one of the six Coast Guard ships that I served in had a highly capable piloting team when I went aboard. That was a large seagoing tug, with a piloting team led by an outstanding Chief Quartermaster. I was the Operations Officer and Navigator. On many visits to Coast Guard ships other than the ones on which I was stationed, it was rare to see a piloting team functioning at peak levels. This is admittedly a small sample, but indicates that even our own ships with good equipment and fine people may not have the training, dedication, and practice to form a quality piloting team.

Preparation

It should be obvious that a navigator must prepare the equipment, brief any assistants, correct the paper chart, affix it to the chart table, lay out the courses, measure distances, draw slide lines for turns, and align the parallel motion protractor, well before entering confined waters. The time and effort just to keep the necessary paper charts up-to-date is extensive and tedious. The navigator must study the available landmarks and aids to navigation carefully, and obtain an initial visual position. After this is done, it is possible to obtain reliable visual fixes. This is in addition to the usual tasks of planning the route, determining the predicted tide and current data, and calculating the estimated time of arrival at various key locations.

Identifying objects

The navigator must identify each fixed object in visual or radar range unambiguously. Visualizing a horizontal view from a flat plan-view chart is a learned skill. It also requires skill and practice in each specific bay or harbor to identify charted features quickly. A navigator identifies large fixed aids to navigation from their characteristics, and tentatively identifies charted man-made structures and prominent terrain features. It is commonplace for a building that was prominent when the chart survey was made to be obscured by newer buildings, or to be torn down. New tanks and towers are built, and cause confusion.

The navigator plots an initial fix with lines of position to each object. A "tight" three or four line fix is evidence of correct identification. Later fixes will verify this, or may reveal that one of the objects was mis-identified. The navigator remembers the reliable objects carefully, and learns to identify them from various angles and distances. This is by no means a casual effort. It is essential to rapid and reliable piloting.

Analysis and cross-checking

A navigator must continually check each piece of data against others. This is necessary to ensure that the objects used for bearings are correlated with the objects shown on the chart. It is vital to check each fix against the depth, and to check the fix against a dead reckoning (DR) position. This cross-checking is important regardless of the source of fix data: visual, radar, or electronic.

In visual navigation, it is necessary to detect occasional erroneous bearings to an object. The navigator also must analyze each fix to determine when the ship's movement along the track degrades the quality of the fix. The bearing takers must then switch to a new object ahead, and the plotter must verify its agreement with the fix. Only then can an object that is getting too far astern be dropped, and the new one put to use.

Accuracy

There are accuracy limitations. The accuracy, or even the possibility of using, visual and radar fixes depends heavily on the geometry of the available objects. Unless there are several objects visible or in radar range, these methods are unusable. The angles between the objects affect the ability to achieve an accurate fix. If, as often happens, there are only a few objects in a limited arc of the horizon, accuracy is poor. Visual and radar fixes have errors that vary with the angles between objects and with the distances to them, but it is difficult to calculate the probable error for a fix. In practice, a navigator searches for objects that give "good" angles on the plot; that is, the angles between the LOPs are not overly acute. Annex A includes information on accuracy of visual and radar fixes—which is seldom better than +/- 30 to 60 yards, 95% of the time, in typical deep-draft ship channels.

Workload

Modern electronic position-fixing and plotting systems have been designed to reduce the navigator's workload. It has become obvious that navigators aboard ships with satellite navigation systems coupled with electronic chart plotters rely on them heavily. Unfortunately, navigators have neglected some of the other important tasks such as verification, cross-checking, and dead reckoning. Using high-accuracy electronic position fixing receivers has been accompanied with a significant decrease in their skill level for traditional position-fixing. In addition, different receiver and chart plotter manufacturers use a bewildering variety of procedures to accomplish various tasks. Ship officers often are low on the learning curve when going to a new ship, or when new equipment is installed.

It should be noted again that obtaining accurate, reliable fixes is only one part of navigation. Planning the route with adequate safety margins, calculating tide and current, and keeping situational awareness are essential to safety. It is also vital to project the ship's track ahead, in order to see whether the path crosses danger areas, and when. A navigator usually does this by plotting the ship's course and distance from a fix to the next turn point, and calculating the estimated time interval. This produces a continuous series of DR positions. The accident reports bulge with accounts of watch officers who have failed to verify the electronic position, or have failed to use that information correctly.

Calculating and plotting new DRs is especially important when the ship changes course. The groundings are too numerous to list when a ship has changed course to avoid one hazard such as a ship, and has run aground on a rock or a shoal. The navigator should also compare the DR positions with fixes, to (a) reveal errors, and (b) determine the set and drift of the current. There is no provision in chart plotters coupled with GPS or Loran-C to accomplish these tasks—tasks that are essential to safety.

In time, it may be practical to design chart plotters to help with some of these tasks, but the design work lies ahead. I know of nothing that has been done to continue Jack Herther's pioneering work on this idea since it ended over 30 years ago. It took many decades to develop semi-automatic radar plotting for collision avoidance, a far simpler problem.

There has been a worldwide trend to reduce ship manning, particularly aboard ships plying coastwise routes. For a typical example, the tugs *Forward* and *Onward* , with crews of seven, each push integrated barges that carry over twice the tonnage of a T-2 tanker on U.S. coastwise routes. These and similar reductions in manning, often to a one-man bridge, has been followed by a sharp increase in groundings. Reference (5) contains an excellent analysis of this situation.

Radar navigation

Radar is a superb navigation instrument. In poor visibility, traditional navigation shifts primarily to radar, depthfinder, gyrocompass, speed log, watch, and lookouts watching for nearby objects and listening for sound signals. Radar navigation in confined waters is notoriously more difficult than visual navigation, or, for that matter, than using radar for collision avoidance in the open ocean. The workload for radar navigation is significantly higher than for visual navigation, and the position accuracy is lower. There is the additional task in low visibility of collision-avoidance plotting on radar, which adds to the navigation workload significantly. Manning reductions have further degraded the ability to do these two vital tasks simultaneously.

In practice, the pilot of a ship within a buoyed channel in low visibility relies heavily on the buoys, with the radar set to a short range scale. While this process works, it depends almost completely on the buoys remaining on station, and cannot deliver accurate geographic positions. Piloting depends on highly skilled people who are intimately familiar with the specific harbor and with various ship characteristics. Ship pilots are beginning to use electronic data from GPS receivers, but knowing landmarks, channel configurations, tidal current peculiarities, and new hazards are vital to successful ship pilotage.

Navigating when GPS becomes inoperative

A plotting team having the equipment and the necessary trained and experienced people can navigate safely if the electronic system is inoperative when the ship enters pilot waters. In that case, they have time to plan, identify objects, determine an initial position, and plot subsequent positions. However, if GPS fails while the ship is in narrow waters, they will require a significant length of time to begin accurate visual or radar navigation.

Detecting electronic fix errors

In order to use visual or radar navigation to detect position drifts in GPS, a piloting team must work continuously to maintain an up-to-the-minute plot. This in itself is an onerous burden in confined waters, and is seldom done. In addition, the fixes may be entirely adequate for navigation, yet not be in a form to compare with the GPS receiver. In order to move the fixes to a chart plotter or compare them with a receiver, it is necessary to measure their latitude and longitude on the paper chart. This is a manual, detailed, time-consuming, and error-prone process. In short, only a second, independent, continuous instrument or receiver can adequately detect gradual degradation in the primary position-fixing receiver.

Automatic Identification System requirements

The best of traditional navigation cannot possibly meet the requirements of the required Automatic Identification System (AIS). The accuracy is too low, and the fix interval is far longer than the required two to ten second interval. AIS requires latitude and longitude to be specified to 0.0001 minutes (around 0.2 meters), which is impossible to obtain with visual or radar navigation. AIS requires course over the ground to 0.1° and speed over the ground inputs to 0.1 knot, also every two to ten seconds. Even if these data could be obtained by traditional methods, manual input to AIS is tedious, time-consuming, and subject to errors. Only a parallel, independent electronic or possibly an inertial position-fixing system can meet the AIS requirements, should the primary electronic system or receiver fail. At the present state of the art, only Navy submarines have suitably accurate and reliable multiple-set inertial navigation equipment installed.

Summary

Traditional navigation has excellent freedom from using external man-made electronic signals. It has a long history of success, along with some spectacular failures. Celestial navigation is the one form of traditional navigation that can be a reliable backup to satellite based systems when the ship is well at sea. It is limited to infrequent fixes, with an accuracy on the order of one to two miles. It can be a suitable backup despite its time and accuracy limitations, while the ship is in open waters free of shoals. It is much easier than in years past, since a navigator can use one of several computer programs to do the calculations, and in some cases the plotting. Nevertheless celestial navigation is a dying skill.

Nearer land, visual and radar accuracy and the intervals between fixes are a very poor second to electronic position data. DGPS and WAAS enhanced GPS receivers deliver fixes at very short intervals that are roughly an order of magnitude more accurate than visual or radar fixes. Traditional navigation in confined waters requires a great deal of highly skilled work. It is not susceptible to a quick start following an electronic equipment failure.

At the present time, very, very few ships have the additional personnel and the requirement to keep an accurate traditional plot in pilot waters. Even those that do so cannot detect drift-type errors in the primary electronic positioning system in short intervals of time. To meet these requirements, a navigator must have an independent, continuous, accurate, reliable source of positioning data. Galileo and Glonass can help in the future, but both will be subject to interference in the same general frequency bands as GPS. To date, only Loran-C (and inertial for the short run) equipment can meet these requirements in U.S. waters.

“This vessel would never hit the sand because this ship has all the advanced technology it needs to prevent something like that from happening.” Captain Nicholas Aslanis of the Royal Majesty to a passenger, prior to the grounding near Nantucket, on 10 June, 1995.

Captain Bill Brogdon USCG (ret)
25 October, 2006

References:

1. The American Practical Navigator, by Nathaniel Bowditch, NVP Pub 9, 1995
    Chapter 7 Dead Reckoning
    Chapter 8 Piloting
    Chapter 13 Radar Navigation
    Chapter 23 Navigational Errors

2. United States Map Accuracy Standards, U.S. Bureau of the Budget, 1947

3. National Ocean Survey Chart 12367, New York Harbor, 1:40,000

4. Radar Navigation Manual, DMAHTC Pub 1310, 1994
Chapter 4, Radar Navigation

5. Marine Accident Investigation Branch (UK) Bridge Watchkeeping Safety Study 1/2004

6. 33 CFR § 164.46 Automatic Identification System (AIS)

7. International Maritime Organization Standards for Automatic Identification Systems, Resolution MSC.74(69), 1998

APPENDIX A to Traditional Navigation in Pilot Waters

Accuracy

Visual and radar fix accuracy depends on the distances to the target objects, the angles between them, and the accuracy of the measurements. In many areas where accurate navigation is essential, such as traffic separation schemes, there are no suitable objects in range other than occasional buoys. Buoys are highly useful, but are visible only at short range, and are not in fixed locations. A typical buoy moves back and forth with the tidal current with a radius equal to one and a half to two times the water depth. Buoys also can drag off-station, and become quite misleading.

Visual fixes

The accuracy of a visual fix depends on the accuracy of the plotted object on the chart, the chart scale, the accuracy of the bearings, the distance to each object, the line of position (LOP) crossing angles, and the accuracy of the plotted LOPs. A gyro repeater is marked every degree, and should have an error as low as 0.7°. The bearing circle may have some small error on the order of 0.2°. Bearing takers normally read bearings to the nearest degree—or very rarely to 0.5°. It would be reasonable to expect to obtain bearings within 0.9°, 95% of the time, from an ordinary gryo repeater.

Then there are errors plotting the LOPs on a chart. The parallel motion protractor's alignment, its small diameter bearing scale, and plotting errors add to the total error. Plotting errors of 0.5° and alignment errors of 0.3° are estimated to be typical. Thus bearings taken within +/- 0.9° of the correct value could be plotted within 1.2° of the correct bearing. A plotted bearing to an object a mile away can be expected to lie within +/- 42 yards of the correct line of bearing, a high percentage of the time.

Visual fix accuracy also depends on the surveying accuracy, and the chart scale and accuracy. Suppose that the chart is 1:40,000 as in New York Harbor, Chart # 12327. This is a typical scale for major harbors. The Coast and Geodetic Survey would survey significant points within +/- 2 meters on this chart. C&GS standards require 90% of well-identified points to be within 0.5mm (1/50th inch) of the true position, at the scale of the chart. On a 1:40,000 scale chart, 0.02" is 67 feet, or about 22 yards. The navigator simply can't see better than about 1/100th of an inch, either at the point for the charted object or along the rule. The small dot indicating a fixed lighted aid to navigation is about 0.07mm in diameter, and the smaller dot inside a circle for an accurately positioned landmark is about 0.4mm. Combining these measurement and plotting errors indicates that quality LOPs could lie within about 48 yards to either side of the true line of bearing at a mile. At a half a mile, the error will be halved, and doubled at two miles.

Objects at various distances show varying distance errors across the line of sight. The LOP crossing angles affect the error ellipse. Seldom does a navigator have an accurate idea, much less a mathematical descriptor, of the error ellipse. As a rule of thumb, few visual fixes would be plotted within 30 yards of the correct position, and these only for fixes taken from nearby objects. (The nearest objects are usually buoys, which are poor choices for fixes due to the fact that they swing in the tidal current.) That error will double with the objects a mile away, as is often the case, say in New York Bay.

Ranges

Certain features that form natural ranges, and aids to navigation ranges, indicate excellent visual lines of position. It is simple to tell when the ship is in line with the range; this provides one reliable and accurate line of position. The ability to detect that the ship is off the range line increases with decreasing distance. At the near end of the range, the angles are large for small distances away from the range line. At the far end of the range, these angles are small, and the range's usefulness decreases. It is quite difficult to determine how far the ship is away from the range line at various distances along the channel, merely by observing the range. In addition, most channels are not marked by ranges.

Radar navigation accuracy

The best targets for visual navigation, such as accurately located building cupolas, church steeples, radio towers, and water tanks, are invisible on radar. The available radar targets are often land features such as points, which are located within 10 meters by the chart survey rather than 2 meters for the targets listed above. Identifying radar targets requires much experience, and there is no backup verification such as looking through binoculars. Prominent shoreline features are distorted by the width of the radar beam, obscuring small gaps and points. This makes it inaccurate to use the tangents of distinct land points, for example, for bearings. The calibration errors associated with radar bearings also detract from their usefulness in navigation.

Navigational radars can measure distances easily, but it is not reasonable to expect accuracy better than +/- 50 yards. However, target features often reduce the accuracy of distance measurements. A shoreline descending steeply into the sea from a hill gives a good echo, but if there is a beach at the foot of the hill, the radar distance will be more than the actual distance to the beach. A sloping beach is a very poor radar target. A point of land may be a "good" target on one bearing, and a poor one when approaching from the opposite direction.

Fixed aids to navigation in the water make excellent radar targets, but they are scarce. A pair of visual range structures, so valuable in clear weather, is almost useless for determining lateral position in a channel when seen on radar. Lining up to go under the center point of a bridge, so easy in clear weather, is rather difficult since the radar simply shows a solid echo stripe extending across the channel.

The skill and effort involved in taking, plotting, and evaluating radar fixes is considerably more demanding than taking visual fixes. It is especially difficult unless the piloting team is experienced in radar navigation and with the area in which the ship is operating. The approach to Argentia, Newfoundland is along a steep coast with many rocky points. It is nearly ideal for radar navigation, yet the well-trained radar plotting teams aboard our Coast Guard Cutters experienced a long period of intense effort, maintaining a good, reliable plot as the ships approached or left that port.

It is commonplace at sea to plot ship targets every six minutes for collision avoidance purposes, for convenience in speed calculations. Radar plotting teams often use the same interval for the much more difficult task of plotting the ship's position near shore. If the navigator uses the Franklin Continuous Plot method near shore, then a significant amount of preparation is necessary.

Radar offers some features that are unavailable when using visual navigation. The parallel offset plot, for example, allows a navigator to pass at a specified distance from a certain fixed target without additional plotting. It is often possible to find a suitable object ahead, and measure its range to determine when to start a turn. But radar fixes remain difficult to plot. Suffice it to say, the accuracy of radar navigation fixes is considerably worse than the accuracy of visual fixes at short range, as when most targets are within a mile. At very long range, radar fixes can be more accurate than visual fixes, due to the ability to detect prominent targets that are difficult to see.

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