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Dead Reckoning

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CHAPTER 10

DEAD RECKONING

DEFINITION AND PURPOSE

1000. Definition and Use

Dead reckoning (DR) is a method for determining the estimated position of a vessel by advancing from a known fix of position along the vessel's ordered course and speed. This can be used to determine where a vessel currently is or where it will be. This is an approximate position; it does not allow for the many errors that can cause a vessel to veer off course such as helmsmen error, compass error, or current and wind.

Dead reckoning helps in predicting landfall, determining distances to objects, predicting arrival times, and evaluating the accuracy of electronic positioning information. It also aids in predicting which celestial bodies will be available for future observation. However, its most important use is in projecting the ship's position in the immediate future and avoiding hazards to navigation.

The navigator should carefully tend his or her DR plot, updating it when required and using it to evaluate external forces acting on his or her ship. Navigators can compare the dead reckoning position to a known fix to determine other forces acting on the vessel, such as wind and current. They can then use all this information to create a more accurate DR plot and stay on course by correcting for the known errors and their effects.

The use of DR when an Electronic Chart Display and Information System (ECDIS) is the primary plotting method can vary with the type of system. An ECDIS can display the ship's heading projected out to show future positions as a function of time, display waypoint information, and/or show progress toward each waypoint in turn.

Presently, marine navigation is in a time of transition with some ships completely paperless and others using a combination of electronic and paper charting. If paper charts are the back up to ECDIS (instead of an additional type-approved ECDIS) it would be prudent to DR as a cross-check to the GPS/GNSS derived position on the ECDIS. Plotting positions on the paper chart should be done at appropriate intervals. The following procedures apply to DR plotting on the traditional paper chart.

CONSTRUCTING THE DEAD RECKONING PLOT

The DR plot should be maintained directly on the chart in use. DR at least two fix intervals ahead while piloting. When transiting on the open ocean, maintain the DR at least four hours ahead of the last fix position. Maintaining the DR plot directly on the chart allows the navigator to evaluate a vessel's future position in relation to charted navigation hazards. It also allows the conning officer and captain to plan course and speed changes required to meet any operational commitments.

This section will discuss how to construct the DR plot.

1001. Measuring Courses and Distances

To measure courses, use the chart's compass rose nearest to the chart area currently in use. Transfer course lines to and from the compass rose using parallel rulers, rolling rulers, or triangles. If using a parallel motion plotter (PMP), simply set the plotter at the desired course and plot that course directly on the chart. Transparent plastic navigation plotters that align with the latitude/longitude grid may also be used.

The navigator can measure direction at any convenient place on a Mercator chart. All the meridians are parallel to each other and a line making an angle with any one makes the same angle with all others. When measuring direction on a conformal chart having nonparallel meridians, use the meridian closest to the area of the chart in use. A common nonconformal projection used is the gnomonic; a gnomonic chart usually contains instructions for measuring direction.

Compass roses may give both true and magnetic directions. True directions are on the outside of the rose; magnetic directions are on the inside. For most purposes, use true directions.

Measure distances using the chart's latitude scale. Although not technically true, assuming that one minute of latitude equals one nautical mile introduces no significant error. The latitude scale on a Mercator chart expands as the latitude increases, therefore one must measure distances on the latitude scale closest to the area of interest when working with small-scale charts. On large-scale charts, such as harbor charts, one can use either the latitude scale or the distance scale provided. To measure long distances on small-scale charts, break the distance into a number of segments and measure each segment at its mid-latitude.

1002. Plotting and Labeling the Course Line and Positions

Draw a new **course line** whenever restarting the DR. To draw a DR, extend the course line from a fix in the direction of the ordered course. Above the course line place a capital C followed by the ordered course in degrees true. Below the course line, place a capital S followed by the speed in knots. Label all course lines and fixes after plotting them because a conning officer or navigator can easily misinterpret an unlabeled line or position.

Enclose a fix from two or more Lines of Position (LOP) by a small circle and label it with the time to the nearest minute, written horizontally. Mark a DR position with a semicircle and the time, written diagonally. Mark an **estimated position (EP)** by a small square and the time, written horizontally. Determining an EP is covered later in this chapter.

Express the time using four digits without punctuation, using either zone time or Greenwich Mean Time (GMT), according to procedure. Label the plot neatly, succinctly,

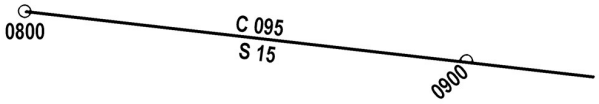

Figure 1002. A course line with labels.

Figure 1002 illustrates this process. The navigator plots and labels the 0800 fix. The conning officer orders a course of 095°T and a speed of 15 knots. The navigator extends the course line from the 0800 fix in a direction of 095°T. S/He calculates that in one hour at 15 knots he will travel 15 nautical miles. S/He measures 15 nautical miles from the 0800 fix position along the course line and marks that point on the course line with a semicircle. S/He labels this DR with the time. Note that, by convention, he labels the fix time horizontally and the DR time diagonally.

THE FOUR RULES OF DEAD RECKONING

1003. Plotting the DR

To effectively maintain the vessel's DR position, the navigator must follow the 4 rules of DR.

Plot the vessel's DR position:

1. At least every hour on the hour.
2. After every change of course or speed.
3. After every fix or running fix.
4. After plotting a single line of position.

Figure 1003 illustrates applying these rules. Clearing the harbor at 0900, the navigator obtains a last visual fix. This is called **taking departure**, and the position determined is called the **departure**. At the 0900 departure, the conning officer orders a course of 090°T and a speed of 10 knots. The navigator lays out the 090°T course line from the departure.

At 1000, the navigator plots a DR position according to the rule requiring plotting a DR position at least every hour on the hour. At 1030, the conning officer orders a course change to 060°T. The navigator plots the 1030 DR position in accordance with the rule requiring plotting a DR position at every course and speed change. Note that the course line changes at 1030 to 060°T to conform to the new course. At 1100, the conning officer changes course back to 090°T. The navigator plots an 1100 DR due to the course change. Note that, regardless of the course change, an 1100 DR would have been required because of the "every hour on the hour" rule.

At 1200, the conning officer changes course to 180°T and speed to 5 knots. The navigator plots the 1200 DR. At 1300, the navigator obtains a fix. Note that the fix position is offset to the east from the DR position. The navigator determines set and drift from this offset and applies this set and drift to any DR position from 1300 until the next fix to determine an estimated position. S/He also resets the DR to the fix; that is, s/he draws the 180°T course line from the 1300 fix, not the 1300 DR.

1004. Resetting the DR

Reset the DR plot to each fix or running fix in turn. In addition, consider resetting the DR to an inertial estimated position, if an inertial system is installed.

If a navigator has not taken a fix for an extended period of time, the DR plot, not having been reset to a fix, will accumulate time-dependent errors. Over time that error may become so significant that the DR will no longer show the ship's position with acceptable accuracy. If the vessel is equipped with an inertial navigator, the navigator should consider resetting the DR to the inertial estimated position. Some factors to consider when determining whether to reset the DR are:

(1) Time since the last fix and availability of fix information. If it has been a short time since the last fix and fix information may soon become available, it may be advisable to wait for the next fix to reset the DR.

(2) Dynamics of the navigation situation. If, for example, a submerged submarine is operating in the Gulf Stream, fix information is available but operational considerations may preclude the submarine from going to periscope depth

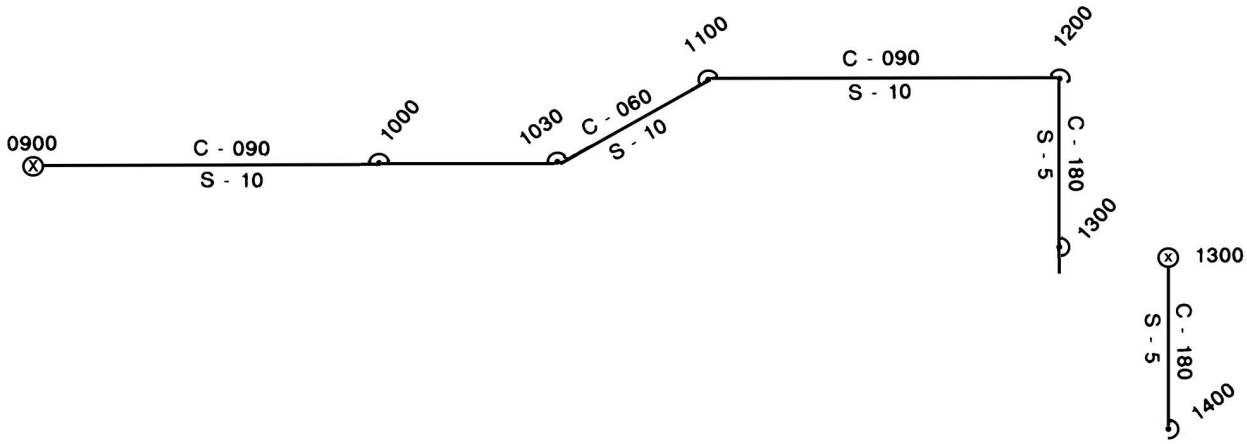

Figure 1003. A typical dead reckoning plot.

to obtain a fix. Similarly, a surface ship with an inertial navigator may be in a dynamic current and suffer a temporary loss of electronic fix equipment. In either case, the fix information will be available shortly but the dynamics of the situation call for a more accurate assessment of the vessel's position. Plotting an inertial EP and resetting the DR to that EP may provide the navigator with a more accurate assessment of the navigation situation.

(3) Reliability and accuracy of the fix source. If a submarine is operating under the ice, for example, only the inertial EP fixes may be available for weeks at a time. Given a high prior correlation between the inertial EP and highly accurate fix systems such as GPS, and the continued proper operation of the inertial navigator, the navigator may decide to reset the DR to the inertial EP.

DEAD RECKONING AND SHIP SAFETY

Properly maintaining a DR plot is important for ship safety. The DR allows the navigator to examine a future position in relation to a planned track. It allows him to anticipate charted hazards and plan appropriate action to avoid them. Recall that the DR position is only approximate. Using a concept called fix expansion compensates for the DR's inaccuracy and allows the navigator to use the DR more effectively to anticipate and avoid danger.

1005. Fix Expansion

Circumstances may arise where a ship steams in the open ocean for extended periods without a fix. This can result from a combination of factors ranging from the inability to obtain celestial fixes to malfunctioning electronic navigation systems. Infrequent fixes are particularly common on submarines. Whatever the reason, in some instances a navigator may find himself in the position of having to steam many hours on DR alone.

Navigators must take precautions to ensure that all hazards to navigation along their path are accounted for by the approximate nature of a DR position. One method which can be used is fix expansion.

Fix expansion takes into account possible errors in the DR calculation caused by factors which tend to affect the vessel's actual course and speed over the ground. The navigator considers all such factors and develops an expanding "error circle" around the DR plot. One of the basic assumptions of fix expansion is that the various individual effects of current, leeway, and **steering error** combine to cause a cumulative error which increases over time, hence, the concept of expansion. While the errors may in fact cancel each other out, the worst case is that they will all be additive, and this is what the navigator must anticipate.

Errors considered in the calculation of fix expansion encompass all errors that can lead to DR inaccuracy. Some of the most important factors are current and wind, compass or gyro error, and steering error. Any method which attempts to determine an error circle must take these factors into account. The navigator can use the magnitude of set and drift calculated from his or her DR plot. See Section 1007. The current's estimated magnitude can be obtained from pilot charts or weather reports. Wind speed can be gathered from weather instruments. Compass error can be found by comparison with an accurate standard or by obtaining an azimuth of the Sun. The navigator determines the effect each of these errors has on his of her course and speed over ground, and applies that error to the fix expansion calculation.

As noted previously, error is a function of time; it grows as the ship proceeds along the track without obtaining a fix. Therefore, the navigator must incorporate the calculated errors into an **error circle** whose radius grows with time. For example, assume the navigator calculates that all

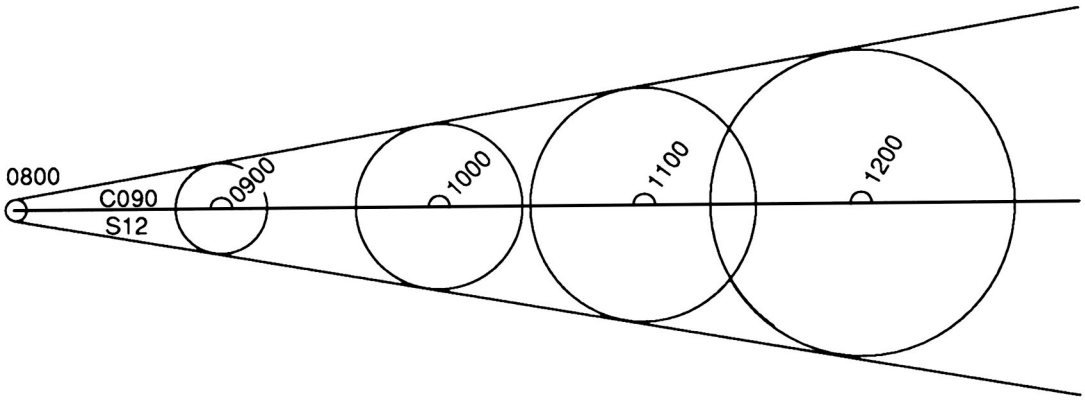

Figure 1005. Fix expansion. All possible positions of the ship lie between the lines tangent to the expanding circles. Examine this area for dangers.

the various sources of error can create a cumulative position error of no more than 2 nm. Then his or her fix expansion error circle would grow at that rate; it would be 2 nm after the first hour, 4 nm after the second, and so on.

At what value should the navigator start this error circle? Recall that a DR is laid out from every fix. All fix sources have a finite absolute accuracy, and the initial error circle should reflect that accuracy. Assume, for example, that a satellite navigation system has an accuracy of 0.5 nm. Then the initial error circle around that fix should be set at 0.5 nm.

First, enclose the fix position in a circle, the radius of which is equal to the accuracy of the system used to obtain the fix. Next, lay out the ordered course and speed from the fix position. Then apply the fix expansion circle to the hourly DRs, increasing the radius of the circle by the error factor each time. In the example given above, the DR after one hour would be enclosed by a circle of radius 2.5 nm (that is, 2 nm of cumulative position error + 0.5 nm of satellite navigation error), after two hours 4.5 nm, and so on. Having encircled the four hour DR positions with the error circles, the navigator then draws two lines originating tangent to the original error circle and simultaneously tangent to the other error circles. The navigator then closely examines the area between the two tangent lines for hazards to navigation. This technique is illustrated in Figure 1005.

The fix expansion encompasses the total area in which the vessel could be located (as long as all sources of error are considered). If any hazards are indicated within the cone, the navigator should be especially alert for those dangers. If, for example, the fix expansion indicates that the vessel may be standing into shoal water, continuously monitor the fathometer. Similarly, if the fix expansion indicates that the vessel might be approaching a charted obstruction, post extra lookouts.

The fix expansion may grow at such a rate that it becomes unwieldy. Obviously, if the fix expansion grows to cover too large an area, it has lost its usefulness as a tool for the navigator, and he or she should obtain a new fix by any available means.

DETERMINING AN ESTIMATED POSITION

An estimated position (EP) is a DR position corrected for the effects of leeway, steering error, and current. This section will briefly discuss the factors that cause the DR position to diverge from the vessel's actual position. It will then discuss calculating set and drift and applying these values to the DR to obtain an estimated position. It will also discuss determining the estimated course and speed made good.

1006. Factors Affecting DR Position Accuracy

Tidal current is the periodic horizontal movement of the sea caused by the tide-affecting gravitational forces of the moon and sun. **Current** is the horizontal movement of the sea caused by meteorological, oceanographic, or topographical effects. From whatever its source, the horizontal motion of the sea is an important dynamic force acting on a vessel.

Set refers to the current's direction, and **drift** refers to the current's speed. **Leeway** is the leeward motion of a vessel due to that component of the wind vector perpendicular to the vessel's track. Leeway and current combine to produce the most pronounced natural dynamic effects on a transiting vessel. Leeway especially affects sailing vessels and high-sided vessels.

In addition to these natural forces, relatively small helmsman and steering compass errors may combine to cause additional error in the DR.

1007. Calculating Set and Drift and Plotting an Esti-

mated Position

It is difficult to quantify the errors discussed above individually. However, the navigator can easily quantify their cumulative effect by comparing simultaneous fix and DR positions. If there are no dynamic forces acting on the vessel and no steering error, the DR position and the fix position will coincide. However, this seldom occurs; the fix is normally offset from the DR by the vector sum of all the errors.

Note again that this methodology provides no means to determine the magnitude of the individual errors. It simply provides the navigator with a measurable representation of their combined effect.

When the navigator measures this combined effect, s/he often refers to it as the "set and drift." Recall from above that these terms technically were restricted to describing current effects. However, even though the fix-to-DR offset is caused by effects in addition to the current, this text will follow the convention of referring to the offset as the set and drift.

The set is the direction from the DR to the fix. The drift is the distance in miles between the DR and the fix divided by the number of hours since the DR was last reset. This is true regardless of the number of changes of course or speed since the last fix. The prudent navigator calculates set and drift at every fix.

To calculate an EP, draw a vector from the DR position in the direction of the set, with the length equal to the product of the drift and the number of hours since the last reset. See Figure 1007. From the 0900 DR position the navigator draws a set and drift vector. The end of that vector marks the 0900 EP. Note that the EP is enclosed in a square and labeled horizontally with the time. Plot and evaluate an EP with every DR position.

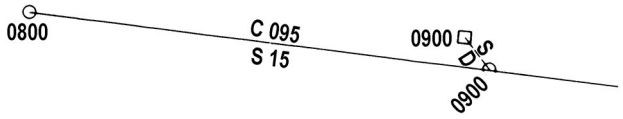

Figure 1007. Determining an estimated position.

1008. Estimated Course and Speed Made Good

The direction of a straight line from the last fix to the EP is the **estimated track made good**. The length of this line divided by the time between the fix and the EP is the **estimated speed made good**.

Solve for the estimated track and speed by using a vector diagram. See the example problems below and refer to Figure 1008a.

Example 1: *A ship on course 080°, speed 10 knots, is steaming through a current having an estimated set of 140° and drift of 2 knots.*
Required: *Estimated track and speed made good.*

Solution: *See Figure 1008a. From A, any convenient point, draw AB, the course and speed of the ship, in direction 080°, for a distance of 10 miles.*
From B draw BC, the set and drift of the current, in direction 140°, for a distance of 2 miles.
The direction and length of AC are the estimated track and speed made good.

Answers: *Estimated track made good 089°, estimated speed made good 11.2 knots.*

To find the course to steer at a given speed to make good a desired course, plot the current vector from the origin, A, instead of from B. See Figure 1008b.

Example 2: *The captain desires to make good a course of 095° through a current having a set of 170° and a drift of 2.5 knots, using a speed of 12 knots.*
Required: *The course to steer and the speed made good.*

Solution: *See Figure 1008b. From A, any convenient point, draw line AB extending in the direction of the course to be made good, 095°.*
From A draw AC, the set and drift of the current.
Using C as a center, swing an arc of radius CD, the speed through the water (12 knots), intersecting line AB at D.
Measure the direction of line CD, 083.5°. This is the course to steer.
Measure the length AD, 12.4 knots. This is the speed made good.

Answers: *Course to steer 083.5°, speed made good 12.4 knots.*

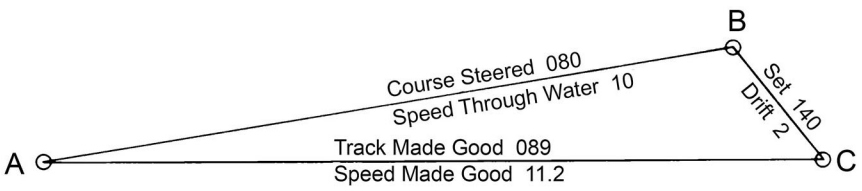

Figure 1008a. Finding track and speed made good through a current.

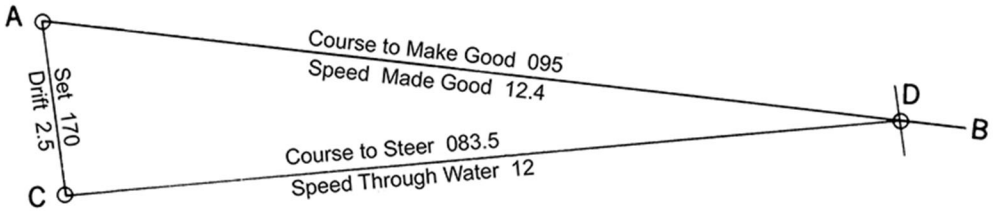

Figure 1008b. Finding the course to steer at a given speed to make good a given course through a current.

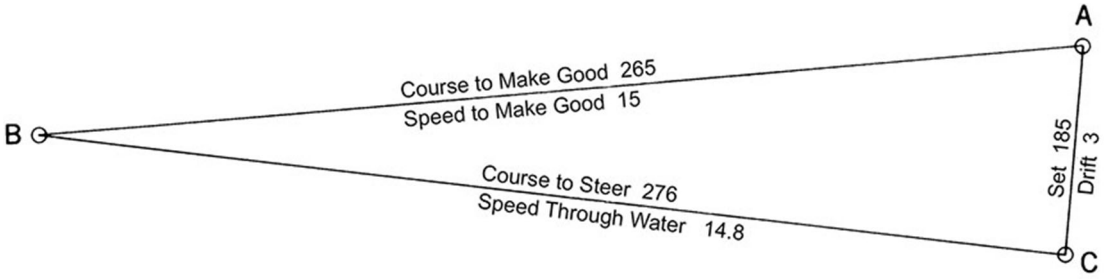

Figure 1008c. Finding course to steer and speed to use to make good a given course and speed through the current.

To find the course to steer and the speed to use to make good a desired course and speed, proceed as follows:
See Figure 1008c.

Example 3: *The captain desires to make good a course of 265° and a speed of 15 knots through a current having a set of 185° and a drift of 3 knots.*
Required: *The course to steer and the speed to use.*

Solution: *See Figure 1008c. From A, any convenient point, draw AB in the direction of the course to be made good, 265° and for length equal to the speed to be made good, 15 knots.*

From A draw AC, the set and drift of the current.

Draw a straight line from C to B. The direction of this line, 276°, is the required course to steer; and the length, 14.8 knots, is the required speed.

Answers: *Course to steer 276°, speed to use 14.8 knots.*