8.0 Navigating with Radar - Part One

8.1 Collision Regulations when navigating with radar

Note: All vessel operators are required to be familiar with the Collision Regulations (**COLREGS**). Installing a radar set brings additional obligations upon the skipper under these regulations. It is not the purpose of this course to discuss **COLREGS**; however, a review of Rules 2, 5, 6, 7, 8 and 19 is strongly advised. Rules 6, 7, and 19 make particular reference to radar, its **competent operation** and **use** under maritime law. Extracts from the Canada Shipping Act are appended to this course, as a **COLREGS** attachment, for your information.

8.2 Navigating with radar

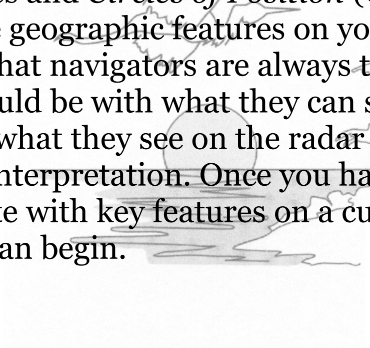
The title of this section may be a misnomer! Basic radar is a navigation *aid* rather than a navigation *positioning device* like GPS or LORAN-C. These units require external signals to operate. Radar itself does not, and cannot, tell you where you are. However, unlike GPS, radar can confirm, with considerable accuracy, where you **actually** are on your chart and what is around you. If you have been following proper navigating practices and have at least a current DR or EP, radar will confirm, or even fix, your position accurately in relation to known features **within your area of radar coverage**. The area of radar coverage is constrained by the height of the antenna and what objects the radar can “see” from that point. Radar cannot see around or through solid objects. The operator should become familiar with the **real** limits of the particular equipment and its installation.

The “picture” produced by a small marine radar is degraded by the physical processes and limitations within the equipment itself.

Now that we have had a good look into the insides of, and outside influences upon, our radar set, we can relate these facts and figures to the practical use of the radar system to safely navigate our boat. Radar may not tell you precisely **where** you are but it can tell you very accurately **what** is around you.

8.3 The radar fix

Properly calibrated radar provides us with extremely accurate range information and reasonably precise azimuth information. While piloting, these can be used to obtain good to excellent fixes and *Circles of Position* (COPs). From a sound DR plot you can initially correlate the geographic features on your chart with the objects painting on your radar display. Note that navigators are always taught to correlate the map/chart features from where they should be with what they can see “out-there”. This prevents them from trying to rationalize what they see on the radar screen with what is on the chart. This is known to cause misinterpretation. Once you have established that the radar picture does, in fact, correlate with key features on a current chart, the process of establishing a *high confidence fix* can begin.



Once a particular charted navigation aid or distinctive geographic feature is identified painting on radar, the *Variable Range Marker* (VRM) line can be placed over the **nearest edge** of the paint which will give you the precise range to the object as displayed in the VRM text area. The *Electronic Bearing Line* EBL readout **may** give a good indication of the relative bearing to the object depending upon the azimuth, width and clarity of the object's radar echo. In Figure 8.1 below, the EBL2 has been placed approximately half of the known beam-width "in" from the left edge of the radar paint to obtain a more accurate azimuth estimate.

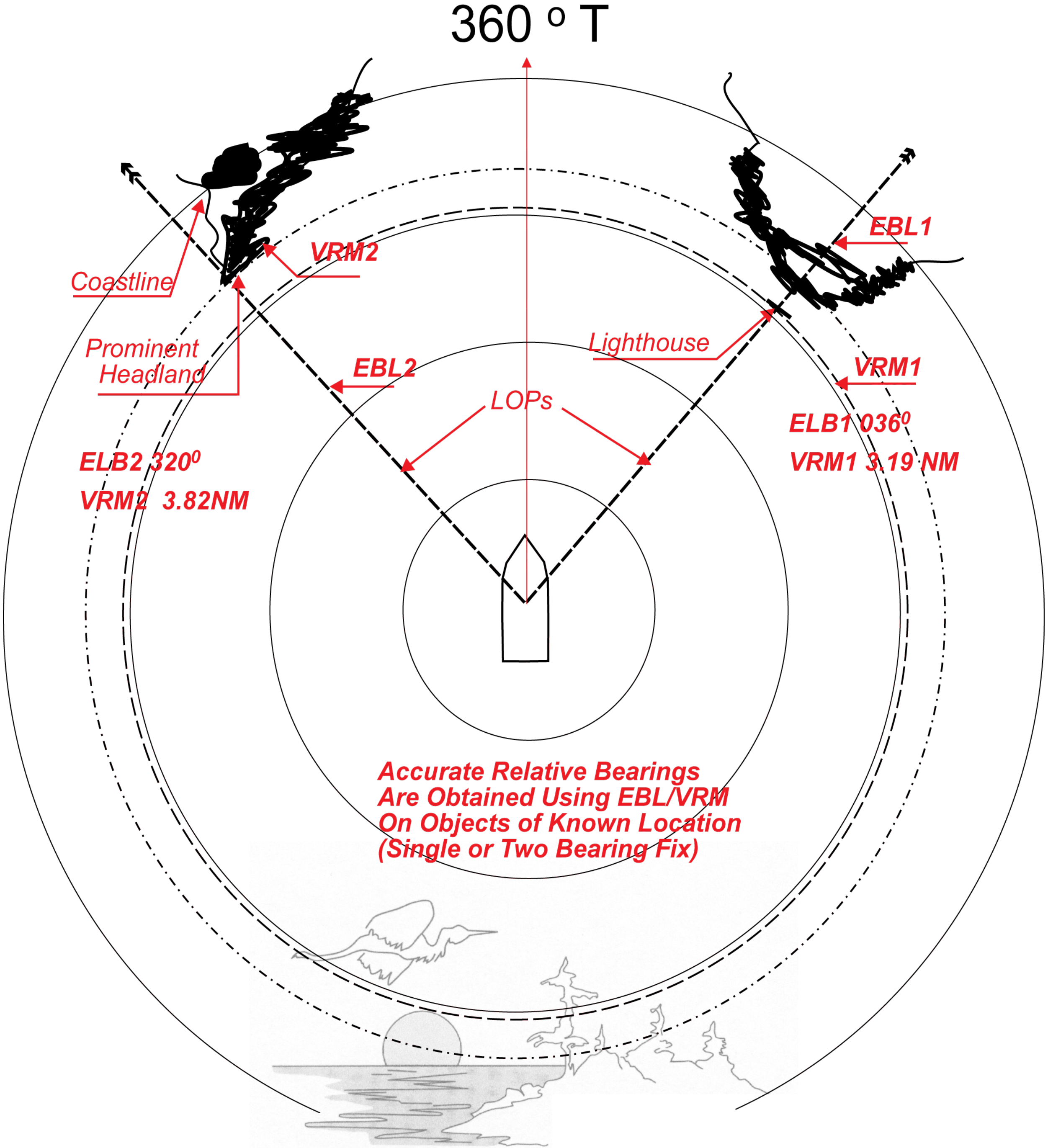


Figure 8.1 Taking bearings on radar

First, when plotted on the chart, the VRM range will give you a very accurate COP, and the EBL back bearing will allow you to establish a reasonable *Estimated Position* (EP). However, if you can identify **two** navigation aids or features on your display, use the VRM values from each object to plot both COPs. The intersection of these COPs will give a very accurate Radar Fix.

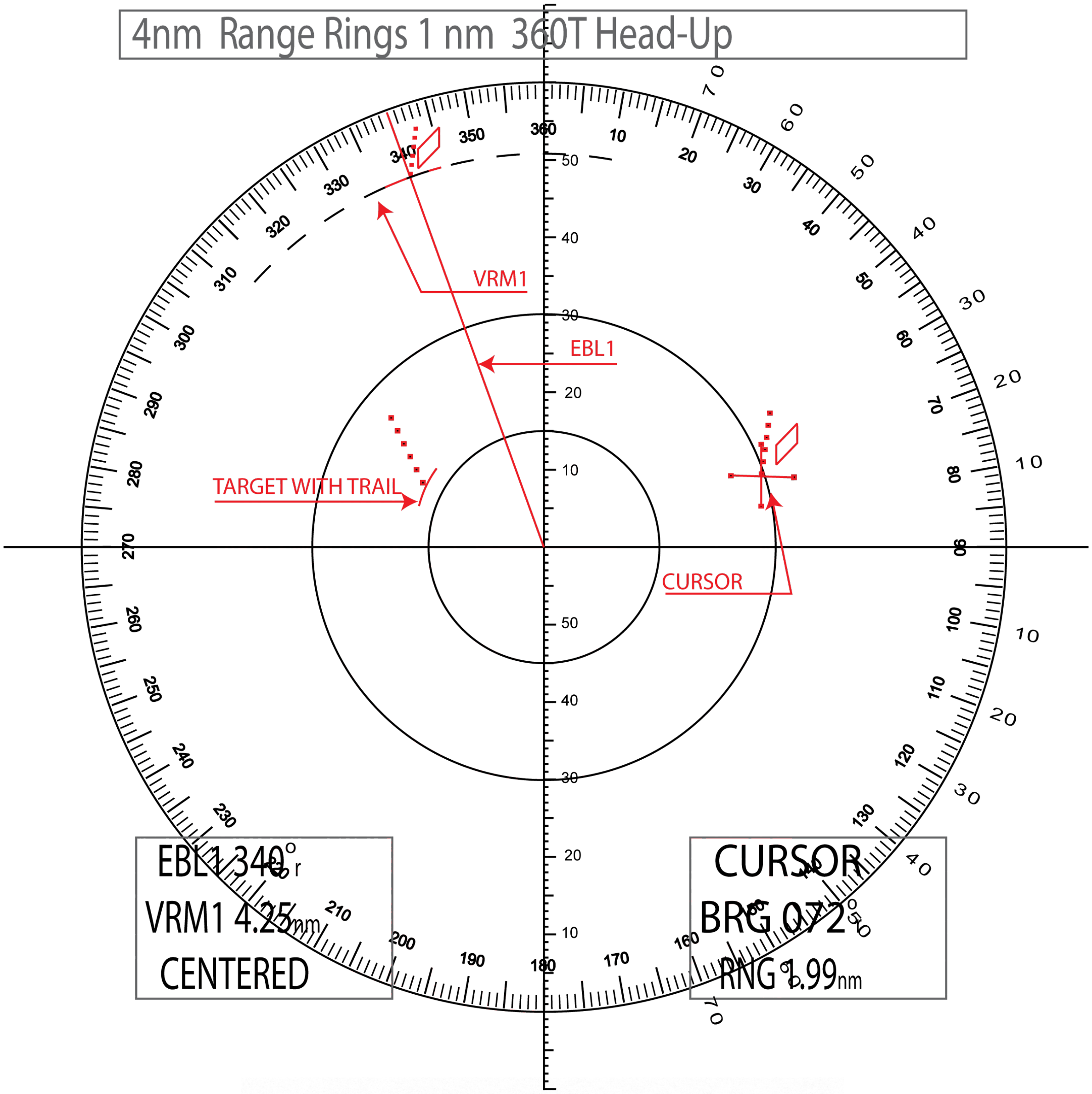


Figure 8.2 VRM/EBL versus Cursor

The radar display drawn in Figure 8.2 does not represent any existing display. It does illustrate a *representative* EBL and VRM combination on the left hand side of the diagram and a cursor type of display on the right hand side. Both of these methods of obtaining bearings and ranges have advantages and disadvantages over each other. For instance, the separate EBL and VRM displays on the left require the operator to set each one separately while the cursor can be positioned with one movement, usually of a trackball type of control. Advantage cursor!

However, the separate EBL can be positioned over a target of interest and left **on that azimuth** while the VRM is updated to check the range of the closing target. As discussed in the next section, a target on a collision course can then be instantly recognized while a cursor has to be continually repositioned over the moving target, and the new azimuth and range read in the text window below. The new azimuth of the target then has to be mentally compared with the old one to recognize any change. Advantage - separate EBL / VRM!

In Figure 8.3 on page 65, the *ranges* to the two buoys, Q Fl R to starboard and the Q Fl G to port, are all that are required to establish the 1200 RDR Fix. This method is easy, quick and very accurate, as long as the closest point of the target echo is used to position either a VRM or a cursor. Also shown is an earlier (1140) radar range and azimuth plotted from the Q Fl R buoy and used to plot an EP.

Looking at Figure 8.3 you might wonder why the 1140 plot is drawn as an EP when it appears to be based upon an azimuth coupled with a very accurate range. The reason is that the radar beam can be as much as 10° wide on one current model and as little as 5.2° on another, when using a 46 cm (18 in) dome antenna. Therefore a precise bearing is dependent upon an accurate azimuth interpretation. The "iffy-ness" of a radar bearing from a "wide" beam reduces the result from a *Fix* to an *Estimated Position*. This EP can be resolved with another *Radar Range* cut on another charted geographic feature.

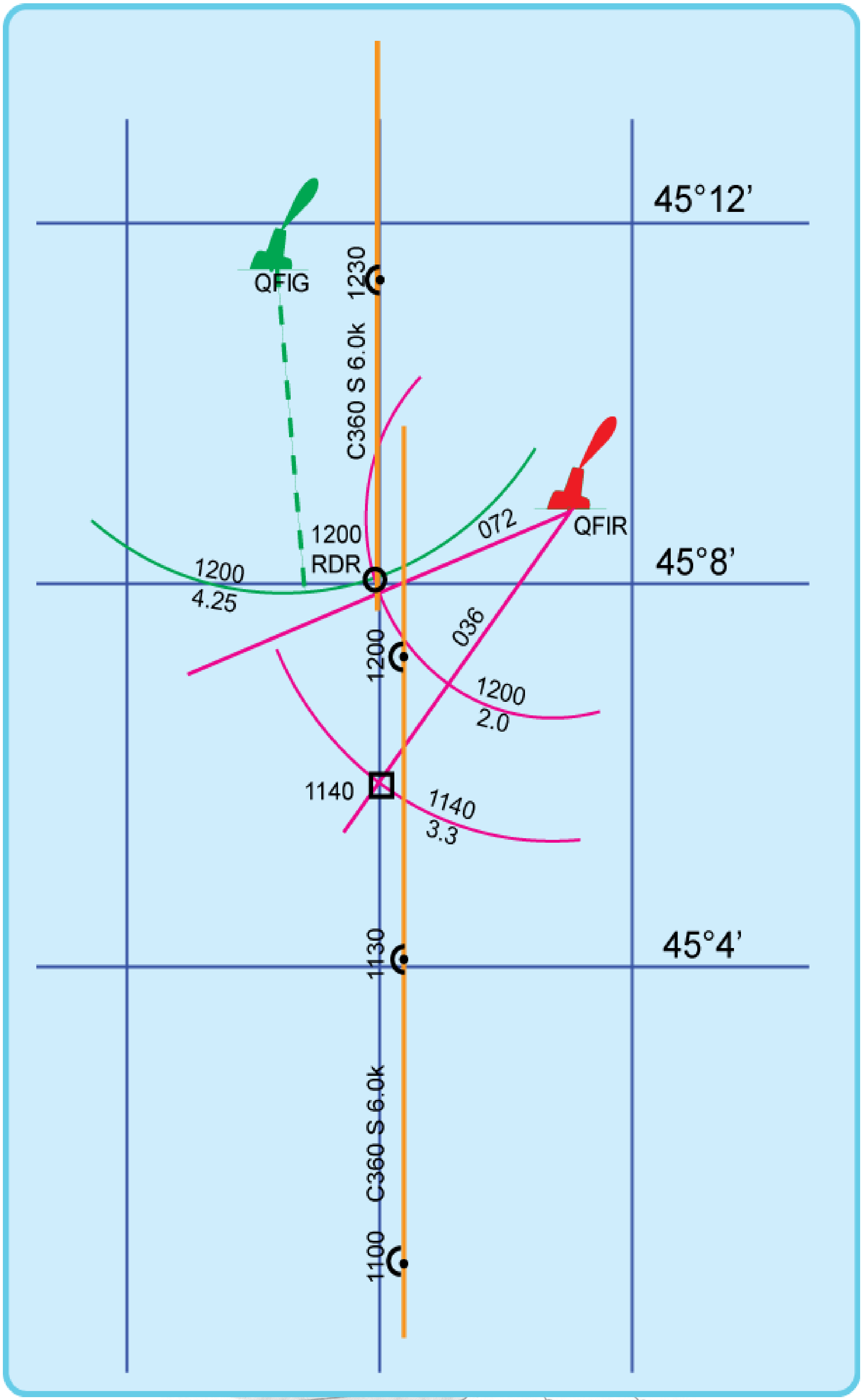


Figure 8.3 Plotting radar ranges and bearings

8.4 Estimating azimuth error

The “one-in-sixty” rule-of-thumb (see Figure 8.4) used by navigators to mentally estimate angular errors can be expressed as:

At a distance of **60 units**, a **1 degree** angle **approximates** a distance of 1 unit (1.0473)

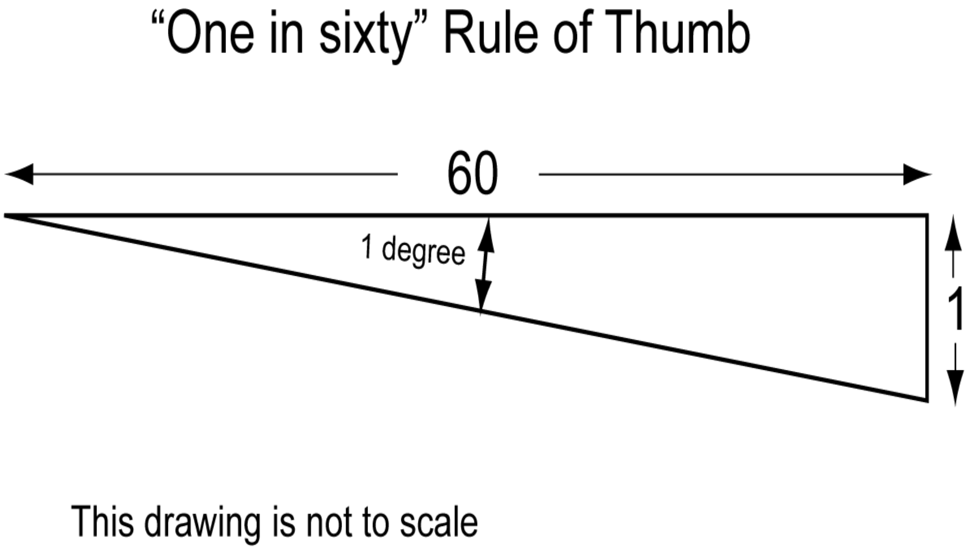


Figure 8.4 One-in-sixty rule

Therefore, at a distance of 5 NM, which is close to the horizon of most recreational radar installations, the maximum likely error to expect will be approximately 5/60 (1/12th) NM **per degree of the antenna’s beam-width**. Thus a radar beam-width of about 5° would result in an *arc of probable error* distance of:

5/12th x 1852 m ≈ 772 m (2500 ft)

The digital display processing used in radar sets today makes the display of this maximum error unlikely. However, the potential for larger than expected errors does exist, and so an azimuth / range position from a single object should only be considered as an EP to prevent later surprises.

Radar is used more often by the watchkeeper as a surveillance and safety tool than by the navigator as a positioning aid. Most of the time it is used to sweep the area ahead of the vessel to see what is out there. In the next few paragraphs we look at the situations where radar can prove itself to be the most practical accessory on board.

8.5 Applied scenarios, or where radar really counts

Consider the three following examples that illustrate the real value of having radar aboard:

a) **offshore** – when you are out of sight of land, the area within your radar coverage;

b) **landfall** – when you are approaching land from an offshore position; and,

c) **estuary** - coastal sailing with variable traffic patterns and shorelines.

8.5.1 Radar offshore

In offshore situations radar is purely a surveillance device. Radar allows the duty watch to scan his/her surroundings for other traffic in the vicinity. Although it probably has a specified maximum range of 16 NM or more, operating recreational marine radar at much more than twice the distance to the radar horizon, reduces the scale of the closer-in area without adding much intelligence about the farthest away area on the display.

With no paintable navigation aids or features in range, radar's major value is to alert the watchkeeper(s) to **approaching** vessels. Once an approaching target has been painted, the watchkeepers must evaluate the risk to their own boat, especially a potential collision course, the rate-of-closure, and the *Closest Point of Approach* (CPA).

The difficulty in trying to visually extract accurate information from the radar display is that your vessel and the painting target are both moving on the display relative to each other. This is well demonstrated in Figure 8.5 on the next page. Notice how the true relationship of the two vessels plotted on the left is distorted on the radar display history on the right.

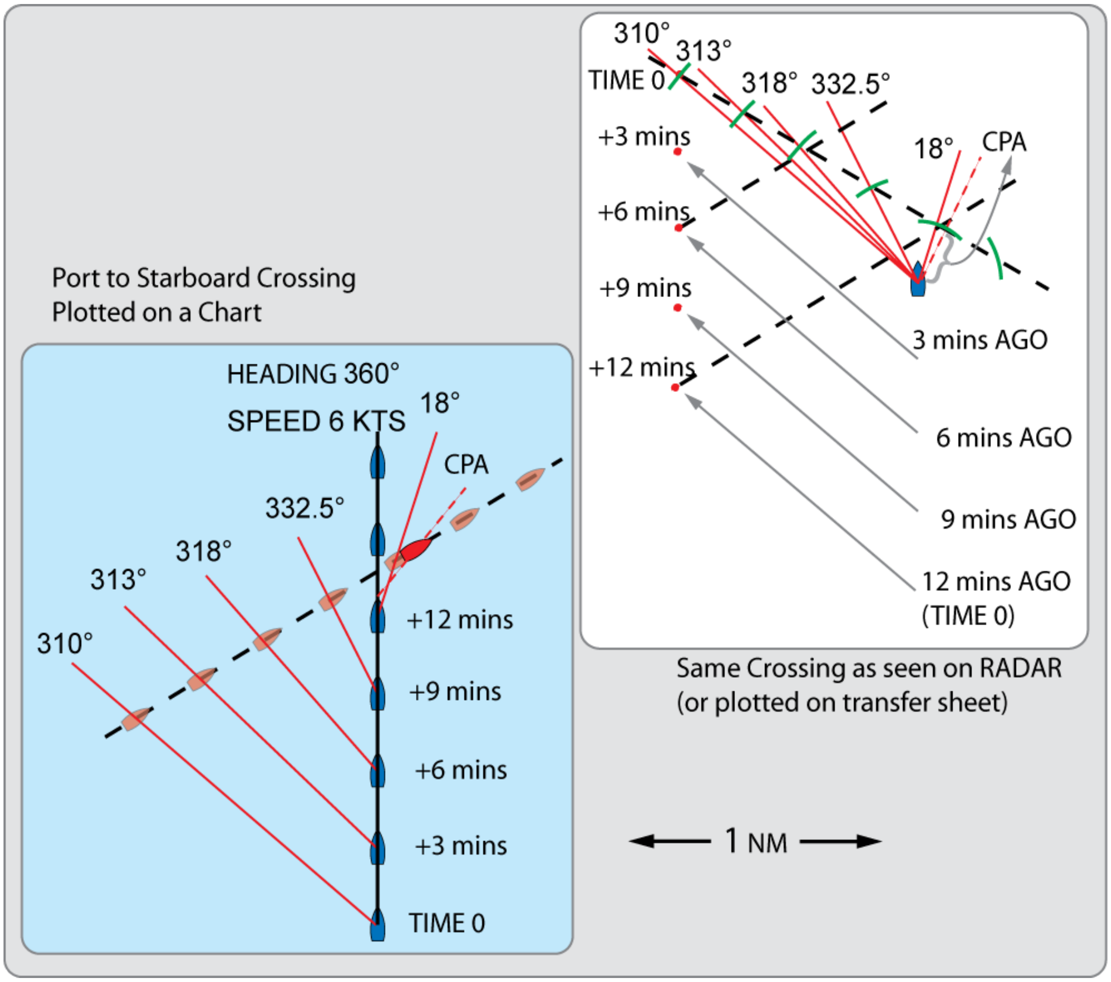
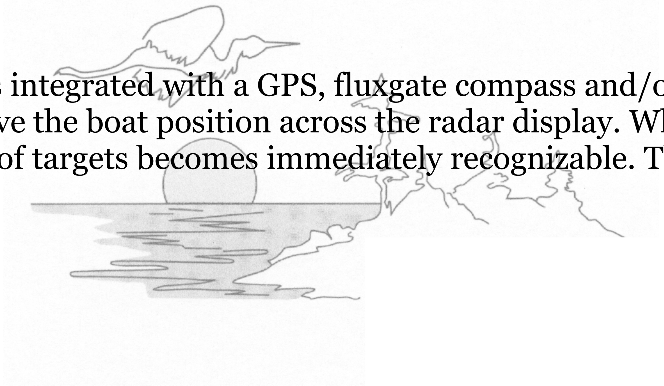


Figure 8.5 Real versus apparent target movement

A basic radar display lacks an obvious critical piece of intelligence for the lookout, the *aspect angle* of the target's approach. The radar picture can convince you that the target is approaching at a quartering bow aspect (from 310° on Figure 8.5 – top right) when it is actually on a beam aspect all the way down to its crossing ahead of you (heading 062° on Figure 8.5 – from lower left at Time 0, *towards* upper right, Now). Because of the **relative** motion of both vessels the target **seems** to be coming towards you from that 310° bearing.

When radar is integrated with a GPS, fluxgate compass and/or laptop computer it has the ability to move the boat position across the radar display. When this capability is used the true aspect of targets becomes immediately recognizable. This will be discussed later, in more detail.



8.5.1.1 Figuring it out, or calculating danger!

In “head-on” situations, the closing rate is the sum of the speed of both vessels. In crossing situations the rate of closure will be somewhat less. In overtaking situations the rate of closure is the speed difference between the two vessels. Any closures in the bow hemisphere can deteriorate into a dangerous situation with ominous rapidity if the watchkeeper fails to establish a prudent course of action **early** in the encounter.

Caution: Documented court evidence suggests that many large commercial vessels may not have a radar watchkeeper, lookout, or even a helmsman in position for many minutes at a time. Having the “right-of-way” must never be taken as a guarantee of your safety.

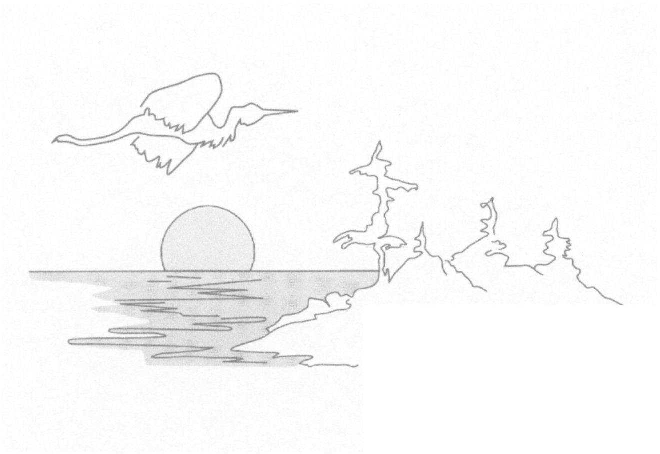
To reiterate, the complicating factor is that the radar display shows the location of a closing vessel, **relative** to our present **heading, speed** and **location**. If we track the target’s position over a short period of time we can record the bearing and *rate of closure* of the target moving towards us. However, we cannot find the target’s aspect (relative heading) or actual speed without doing some plotting of the information in front of us.

8.5.1.2 The collision course!

The best way to try to explain this concept is by the use of a diagram. Figure 8.6 on page 72 illustrates:

1. how a closing situation might look on a radar display; and

2. how a simple scale diagram can be used to interpret the developing situation.



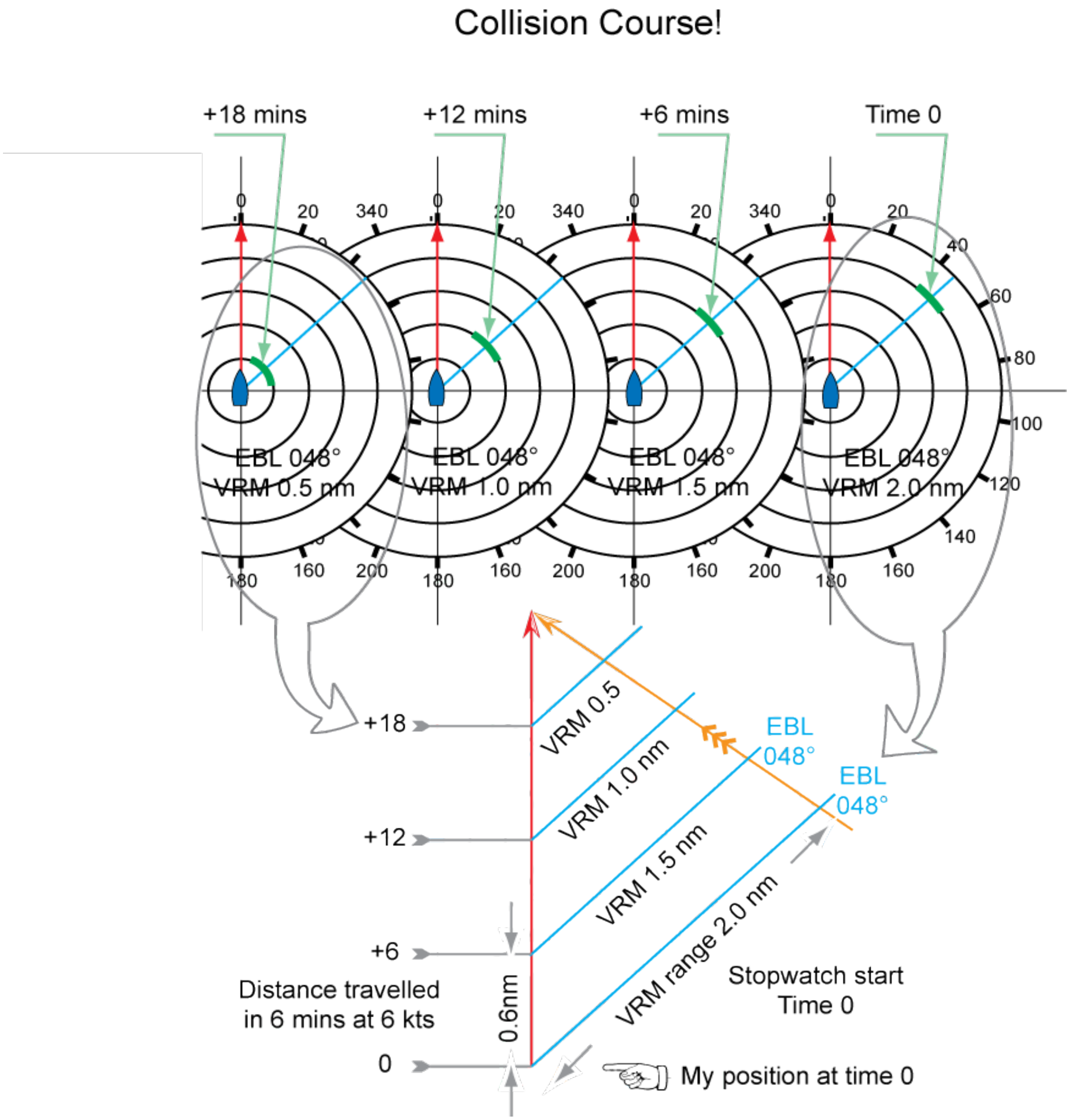


Figure 8.6 Collision course interpretation

Four stylized radar displays are shown across the top of the drawing. They represent snapshots in time, at six-minute intervals, from the oldest (Time 0) on the right, to the most recent (+18 min) on the left. The range scale is 2.5 NM with 0.5 NM range rings. The EBL has been placed over a *track-of-interest* at 2.0 NM (VRM), and a stopwatch has been started to measure the time passage with precision. These steps are essential if the developing situation is to be accurately evaluated.

As time passes, note that the EBL relative bearing **stays constant** at 048° while the VRM distances steadily decrease by 0.5 NM each six-minute interval. What conclusions can the radar watchkeeper glean from these values? The constant bearing immediately suggests that a collision course situation is occurring. Also, that the collision is most likely to occur at the stopwatch time of +24 min. Both of these assumptions are correct, a collision is imminent!

8.5.1.3 Target aspect angle

As the situation is developing and the watchkeeper looks out to try to visually locate the encroaching vessel, what navigation lights would she/he expect to see? From the radar display the target is coming "straight towards" the observer's boat. It is not unreasonable to assume both port and starboard running lights should be in view, but are they?

This would be true if, and only if, the radar being viewed was stationary. However, our vessel is underway at 6.0 kn. This motion of the receiving radar distorts the displayed picture.

Look at the lower half of Figure 8.6 and see how a scale drawing (plot) can reveal the true picture of the relationship between the two vessels.

A suitable scale is chosen and the heading-up display of our boat is drawn as the line marked 360°. At the origin of that heading line the EBL is drawn at the relative bearing of 048°. The VRM reading of 2.0 NM is marked to scale along this bearing line. This line represents the relative bearing and the distance between the two vessels as it existed **at "Time 0",** the start of the stopwatch.

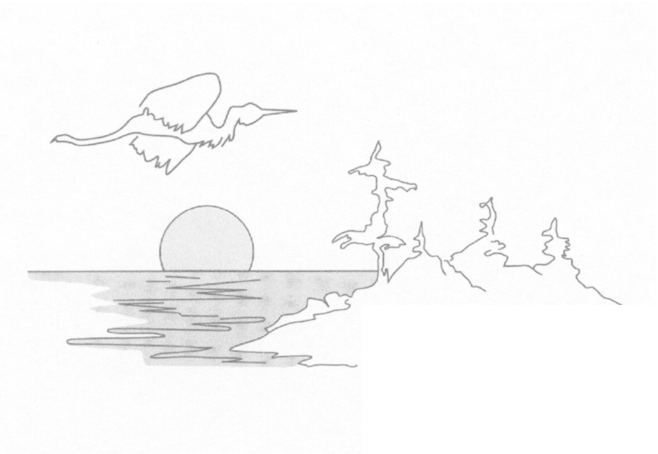
Six minutes later the EBL value is the same but the VRM is now 1.5 NM. In order to accurately insert this new information, we must allow for the motion of our vessel. Six-minute intervals are 1/10th of an hour. Our boat is doing a steady 6.0 kn, therefore it will cover 0.6 NM in six minutes. The origin of the +6 min EBL must be placed to scale 0.6 NM along the heading line. The new EBL can then be drawn and the target's relative position placed along the new bearing, 048°, 1.5 NM, time **+6** min.

This procedure is repeated for the +12 min and +18 min readings. When these locations are connected the true relative motion of the vessels is revealed, the actual (relative) heading of the closing vessel can be measured with a protractor, and the speed calculated by measuring the scale distance travelled over the times noted on the drawing.

Now the questions of the targets aspect angle to our vessel, the running lights we should see (port, stern and perhaps masthead) and most importantly which vessel should initiate avoidance action, can be answered The drawing also confirms that the CPA will be 0.0 NM and a collision is most likely at time +24 min!

The lines of this drawing are vector quantities. That is, because they are drawn to scale, they represent both direction and speed. The first line illustrates the relative heading and speed of our vessel. The second set of lines indicate the bearing and rate of closure of the target-of-interest. Therefore, the line drawn to close the triangle (the resultant) must represent the actual (relative) heading and speed of that target-of-interest.

This method of resolving the problem is very awkward as it requires a plotting surface, graph paper or the like, plotting instruments and an accurate hand. However, the vector triangle for this case can be constructed a different way as shown in Figure 8.7 on the next page.



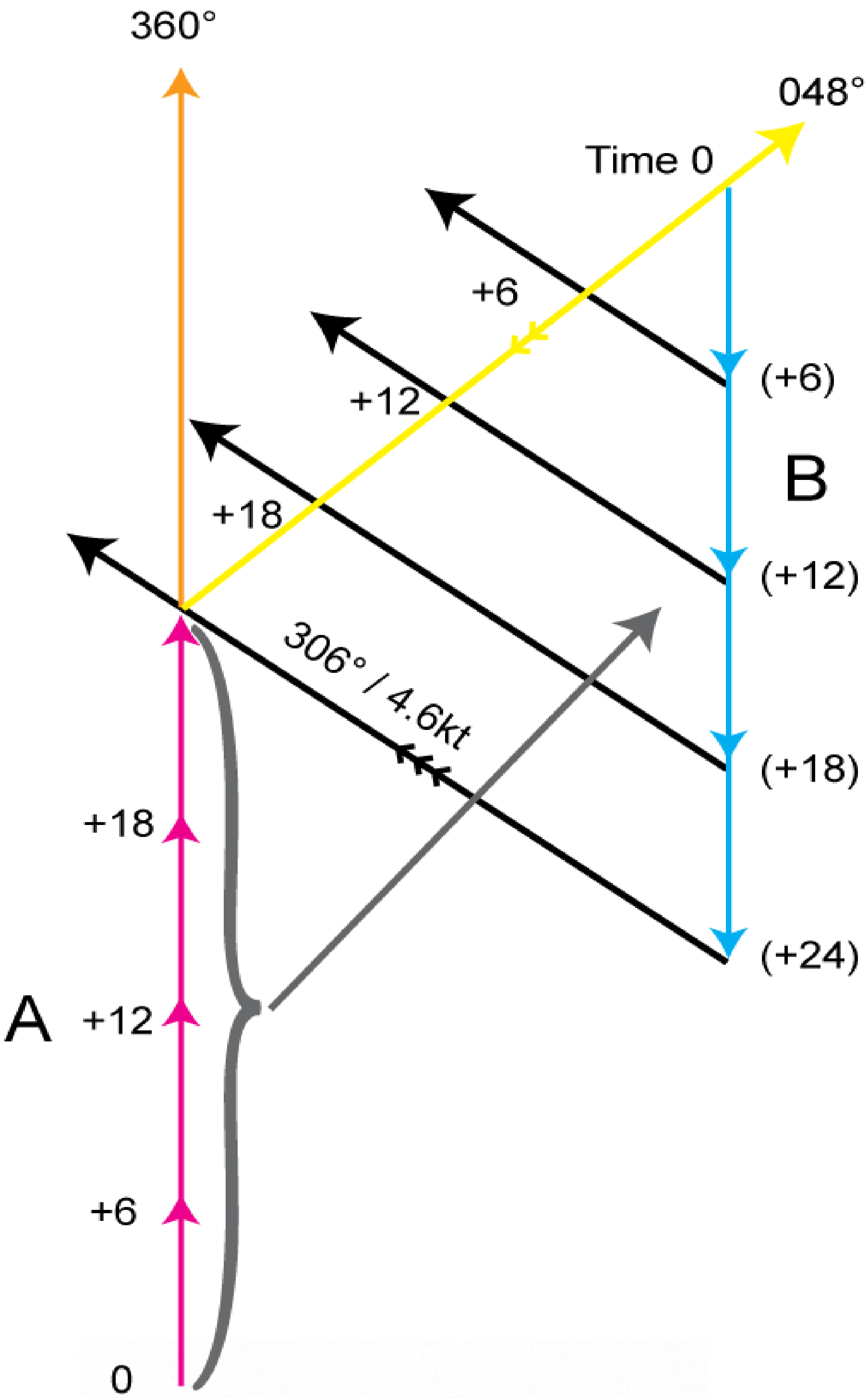


Figure 8.7 Alternative plotting of target closure

Notice that the vector line A, representing our vessel's movement 360°/6.0 kn has been redrawn to originate at the Time 0 point on the target bearing plot, and oriented at 180° (the reciprocal vector).

The same scale (speed value) is used to show distances versus time (+6 min, +12 min, etc.). Now the two +6 min marks can be joined, to quickly give the direction of movement of the target-of-interest and the distance it has moved in the six-minute interval, hence we have an estimate of its actual speed. The results are the same, but the information we desire is available much faster and is easily refined at each subsequent time interval.

There are three commonly used methods of using this vector analysis technique to extract critical information from our radar display.

8.6 Calculating the numbers

8.6.1 By plotting

The classic method of determining the course, speed and CPA of a target vessel is to use a manoeuvring / plotting board, or radar transfer plotting sheets (Figure 8.8).

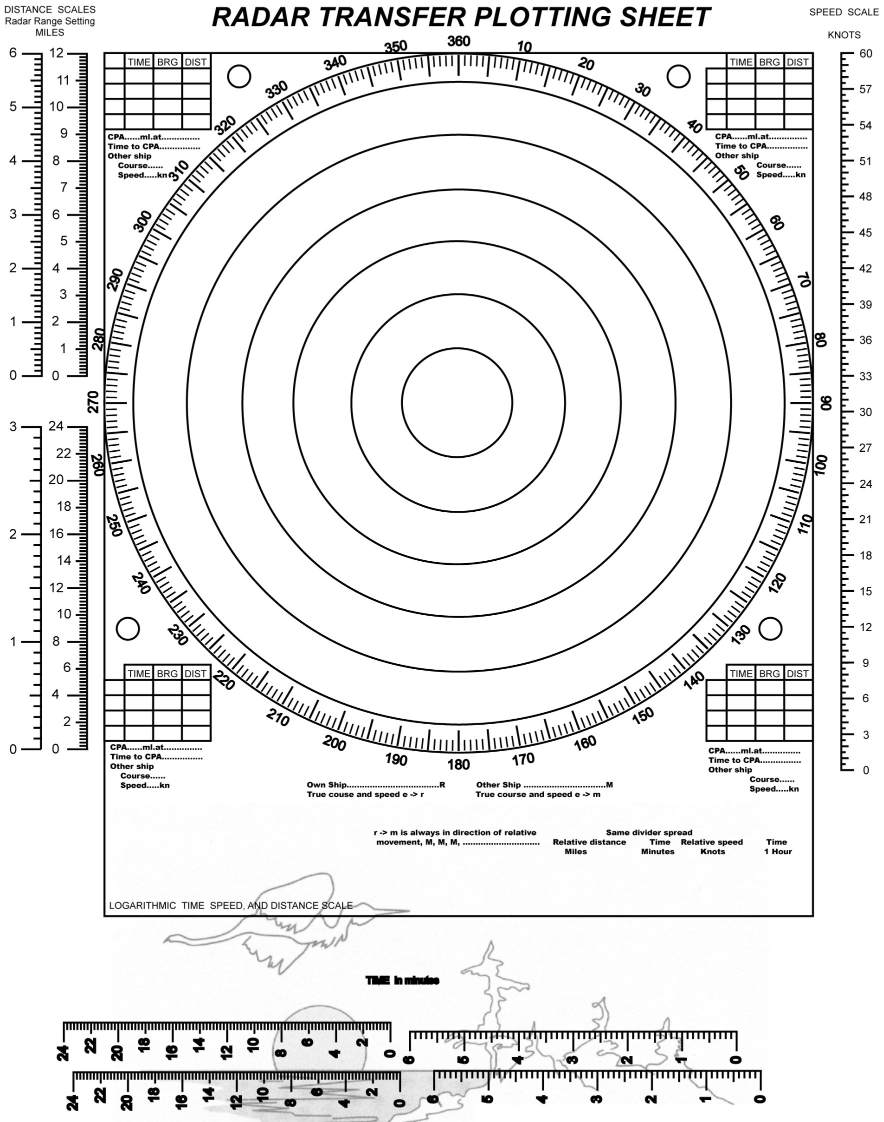


Figure 8.8 Radar Transfer Plotting Format

These boards, or their equivalent paper pads, allow navigators to accurately plot the relative locations of both vessels to scale (see Figure 8.5) using the technique described in the previous paragraphs. After specific periods of time, usually 6 minutes (10% of an hour), the new relative position of the target vessel is plotted and the *reciprocal vector* of their own vessel's movement is also updated on the plot. The positions shown on the lower portion of Figure 8.9 below need not be plotted and are shown for clarity only.

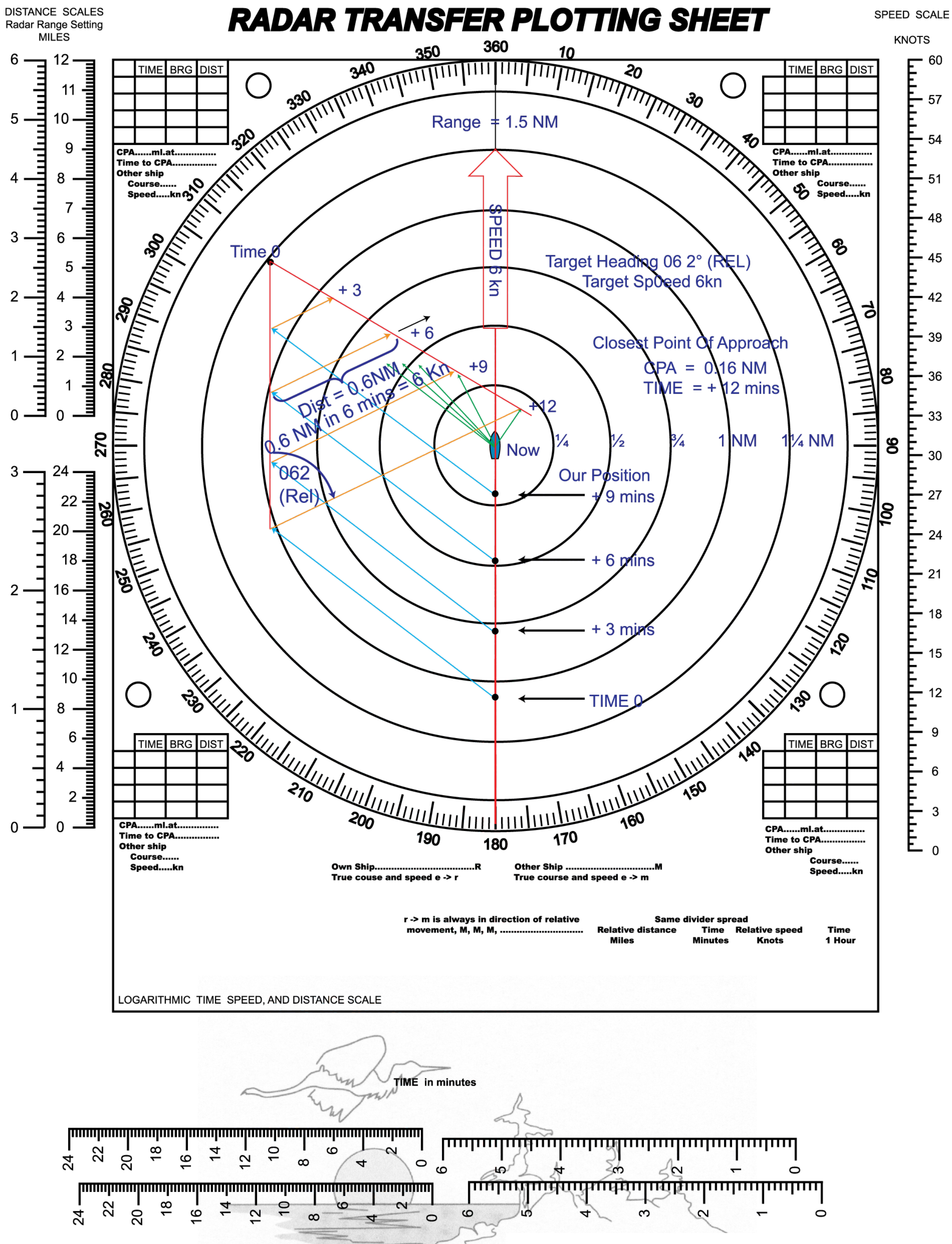


Figure 8.9 Plotting an approach

The actual heading of the target, its speed and its CPA can then be quickly determined from its plotted history. By plotting the developing situation on paper, the decision maker can easily see which direction to steer to safely and expeditiously remove any conflict.

Note the differences between the first example shown in Figures 8.6 and Figure 8.7 and this plot Figure 8.9. In the first example the EBL 048° reading did not change from first pickup until time +24 min where a collision between vessels was likely. In this example the EBL reading is initially increasing slowly as the range decreases. This steadily changing bearing shows the value of using the plotting sheets with the accurate compass rose and range marks overprinted. Also, it allows an accurate assessment of the probable CPA distance and the time it is most likely to occur - very valuable information!

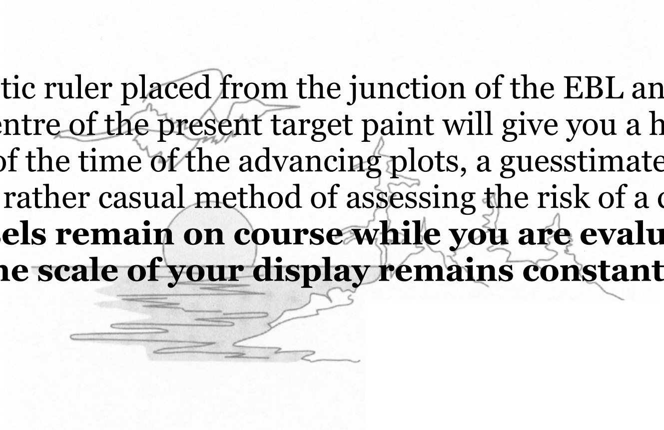
The drawbacks of using this method are that it requires a lighted chart table, “elbow room”, a plotting board or plotting sheets **and time**. Few recreational boaters have these facilities, or are unlikely to be able to conveniently use them. This solution should be considered the best, but least practical, solution. It is the most accurate, but the most arduous, of the three methods introduced here.

8.6.2 By “eyeball”

A second method is “guesstimating” the absolute minimum safety data. Use the EBL and the VRM features of the display to do this. If a target of concern is on a collision course with your vessel, regardless of its direction of approach or the rate-of-closure, its **relative (EBL) angle** will remain the **same** all the way to impact!

Therefore, the first thing the operator must do is place the EBL as precisely as possible through the centre of the target’s paint and **leave** it there! The VRM should be run out and placed on the leading edge of the target paint. As time passes, if the target track **moves away** from the EBL towards your bow, the target will **pass ahead** of your vessel. If subsequent paints **move aft** of the EBL, the target will **pass astern** of you.

A flexible plastic ruler placed from the junction of the EBL and original VRM mark, through the centre of the present target paint will give you a hint as to the CPA. If you have kept track of the time of the advancing plots, a guesstimate of the time of CPA might be made. This rather casual method of assessing the risk of a collision **only works if both vessels remain on course while you are evaluating the situation, and if the scale of your display remains constant.**



The greatest drawback with this evaluation method is its complete lack of a useful history. Any manoeuvring changes to the situation wipe out the value of the “old” EBL setting, and you are back to the beginning. However, in really tight situations this method **can**, and **does** provide the first warning of a possible collision.

Warning: Potential collision course situations can increase the stress on a watchcaptain at an alarming rate.

8.6.3 By “Post-It©”

The third method of evaluating the potential for collision is a compromise between the demanding plotting method and the riskier second method. The key is the proliferation of the 3M Company’s “Post-It©” sticky notes, or their equivalent, which can be stuck directly onto the face of the display without marring its surface.

Using a suitable size of Post-It place marks at intervals corresponding to:

a). the scale of the current display;

b). the speed of the vessel; and,

c). the display range and the boat speed these intervals represent, for future use.

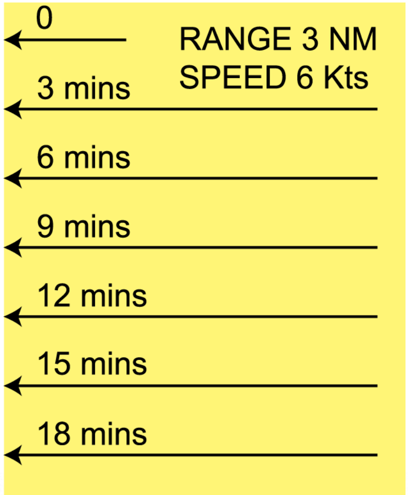


Figure 8.10 The “Post-it” protractor

For instance, if our speed is 6.0 kn, then a scale distance of 0.6 NM intervals would represent the distance our boat will move across the display screen in six minutes (10% of an hour).

Draw lines across the Post-It parallel to the top edge so that it can be used on either side of the display, and mark it with the *display range scale* for future use. The spacing of lines indicates the distance travelled in the chosen time periods (3x minutes).

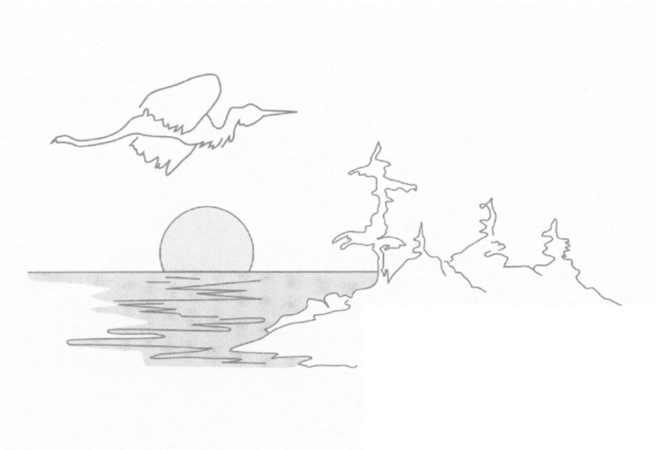
The Time 0 mark may be placed at the upper corner of the Post-it or farther down, if desired, as shown in Figure 8.10.

Carefully place the Time 0 mark of the Post-it over the intersection of the EBL and VRM markers indicating the location of the first timed paint, parallel with the boat's heading (vertically on the display). The remaining time marks will then compensate for the forward movement in three or six-minute intervals.

At precisely six minutes later, a line drawn from the corresponding time line (+ 6 min) edge on the Post-It sticker, through the **current paint** of the target, will graphically show the relative heading of the target. The length of that line (scale distance) will equal (in this case) one tenth of the target's speed in knots.

Looking at Figure 8.11 on page 79, you can easily recognize the same three vectors required to solve the target heading and speed problem, drawn in Figure 8.7 on the display face.

In this illustration the target vector is drawn connecting the 18 min positions for better clarity. (3 x 6 min = 30% of the speed in knots).



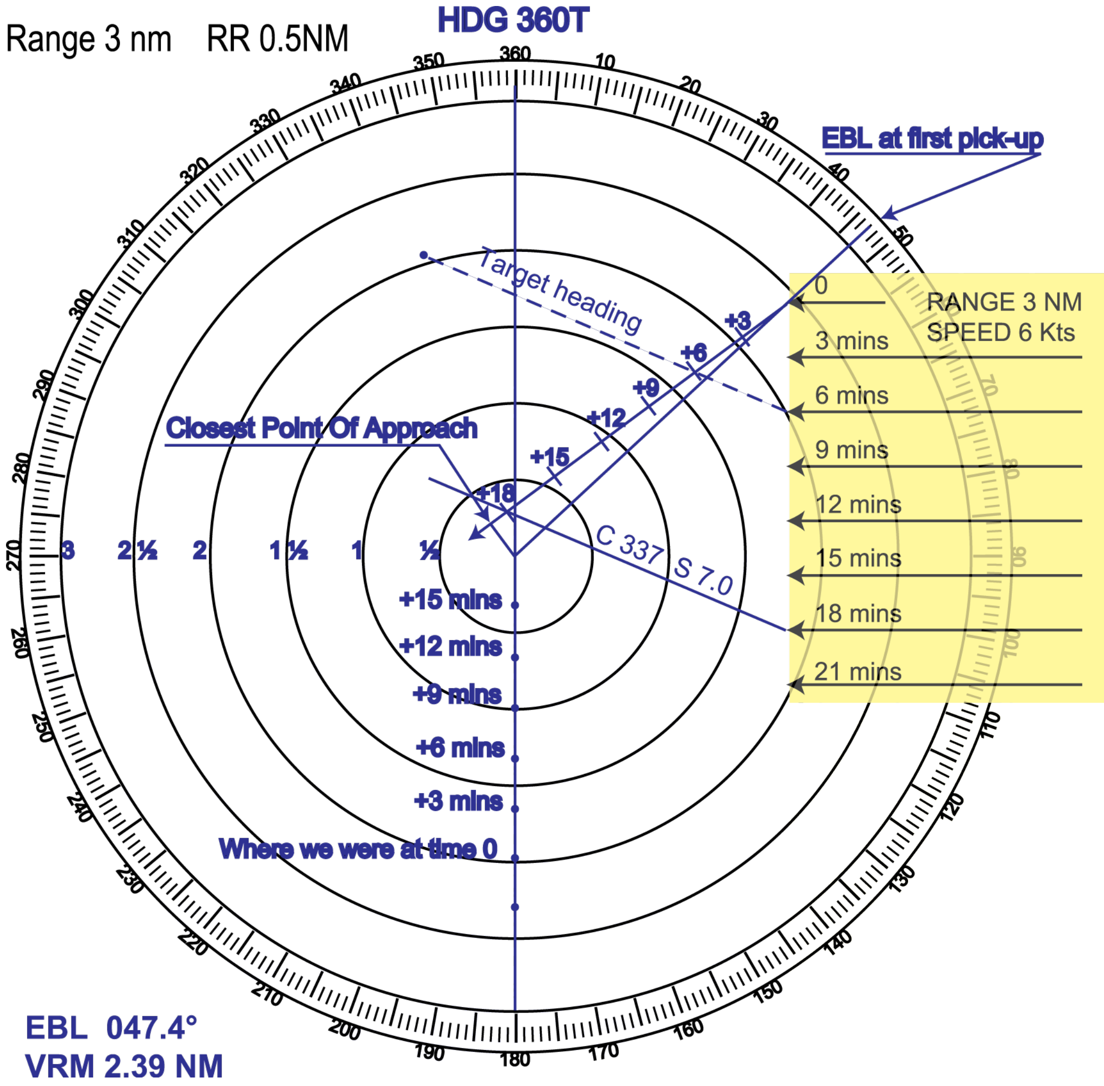


Figure 8.11 The "Post-it" solution

This method allows a fairly accurate assessment of the relative azimuth, distance off and time of the CPA, as you can see in the figure. Again, in situations of very poor visibility, you can see the value of being able to picture the proper orientation of the target (aspect) as it approaches you, thus allowing a watchcaptain to make a more informed change of course with high confidence. This alone is a safety feature that makes the radar set invaluable in crossing situations.

8.6.3.1 Be prepared

This third method of radar track evaluation is recommended for all closing situations, both offshore and in busy waters. Carefully prepared Post-It scales can be located near the display surface. When clearly marked with the current display scale and boat speed they can be expeditiously applied to the display surface before any closing situations escalate.

All three of these methods of calculating danger work in all situations. However, the closer to shore you are operating, the less time you are likely to have to take corrective action. Practising a good zero visibility radar escape procedure on **nice** days might just be worth the effort .

8.7 Summary

- Radar is an excellent aid to safe navigation, but it is not a positioning device.
- A properly calibrated radar set has very accurate range measurement which can be used to update your position plot and provide excellent fixes from charted objects.
- Unlike GPS and Loran-C location devices, radar is a wholly-contained onboard system which has no need for external signals to operate effectively.
- The ability of radar to "see" closing targets when there is low or zero visibility, allows the operator to plot them in such a way as to determine their relative heading and speed with enough time and confidence to take positive avoiding action.
- As potential collision situations are hardest to recognize in very poor visibility, radar operators should practise, and become comfortable with, the CPA plotting methods in this section.

Next - Navigating with radar continued, landfall and estuary

The next section deals with how radar may be used when approaching land from offshore and in a coastal environment closer to shore.