Key notes:

- Relative vectors do not change with speed input, the CPA information is correct (within limitations) and is independent of input.
- Sea-stabilised or water-track mode provides the correct aspect, but with ground-stabilised or ground-track mode the aspect could be wrong. The correct aspect may be required to take a decision on a collision-avoidance manoeuvre.
- Sea-stabilised mode does not indicate whether 'own ship' is being set, but ground-stabilised mode gives a quick indication of how 'own ship' is setting. This implies that sea-stabilised mode should be used for collision avoidance and ground-stabilised for navigation.
- In open sea, if one radar is used off-centre, the other should be centred.

6.2 Plotting

Radar plotting is generally used to report on the radar contacts. Plotting can be carried out manually on a plotting sheet, either by using the reflection plotter or electronically. Regardless of the medium used, good results are produced through a combination of the correct application of the basic methods and the skills of the operator. Navigators should practice plotting skills in clear weather when monitoring can be carried out by other means, such as on visual, and results can be checked against reality or radar simulations, as with trial manoeuvres.

There are a few basic rules that the navigator needs to follow. Keep plotting tools (equipment) available at all times and ready for immediate use. Even basic tasks like keeping the pencils or chinagraph crayons sharpened are essential. Compare clocks and avoid adjustments as they can cause confusion about the current time.

The navigator should select equal time-intervals between observations. Intervals like 3, 6, 10, 12, or 15 minutes are convenient fractions of an hour and lead to sensible arithmetic manipulation. The plotting interval selected should be appropriate to the range scale in use, the speed of 'own vessel' and the approach rates of the target vessels.

Mark the targets on the plotter with an accurate cross or a fine point. Do not use a large blob. Use electronic markers where available. The targets should be given designators at this stage. This approach is very helpful when observing a number of targets simultaneously. For plotting purposes, the actual ranges and bearings should be picked up from these marks. This avoids errors that may be introduced, either due to inaccurate timing or through a change of sequence to the observation and plotting of the targets.

6.2.1 Procedure And Terminology

A basic plot in Example 6.1 demonstrates the vectors and the terminology used for relative plotting, along with some aspects of the procedure.

Example 6.1

A vessel heading 320° T at 21.5 knots, observes another vessel on the radar. These observations were made:

0900	*020°T*	*10´.0*
0906	*025°T*	*8´.1*
0912	*032°.5T*	*6´.4*

Compile a radar report for 0912.

Solution and Comments

Plot the heading line of the observing ship and mark it with the course and speed of 320° T x 21.5 Kts.

Plot the three bearings and ranges. The first one should be labelled 'O' and the final as 'A'. Make a note of the times of each observation next to the relevant mark. Where observations are made on head-up display, the relative bearings may have to be converted to true bearings.

Draw a line of best fit through these points. This is the 'OA' line, the line of relative approach, and run it past the centre of the plotting sheet or display. Mark an arrow in direction 'O' to 'A' and circle it. In actual practice, during real time plotting and before proceeding further, the points should be seen to fall closely on this line and that they are not scattered unduly. See if the points are a similar distance apart. If the distances are uneven for an equal time interval, or the points are asymmetric, it could indicate that either the observed target is in the process of changing course and/or speed or that there are errors with the observations.

The 'OA' line provides information on the risk of collision. If this line passes through the middle of the sheet, the observed vessel is on a collision course. If it does not pass through the middle, as in this example, the distance that it passes from the middle should be determined. This is done by drawing a line perpendicular to the 'OA' line, which passes through the middle of the plot 'B'. The perpendicular meets the 'OA' line at point 'X', which is the CPA. Distance 'BX' is the distance off at the CPA, which is 3´.4. An arc also indicates the CPA distance.

The direction of line 'BX' indicates the bearing of the CPA.

The time of relative approach can also be measured along the 'OA' line. Distances 'OA' and 'AX' should be measured and, in this instance, are found to be 4´.0 and 5´.4. 'OA' is the approach distance covered during the plotting interval.

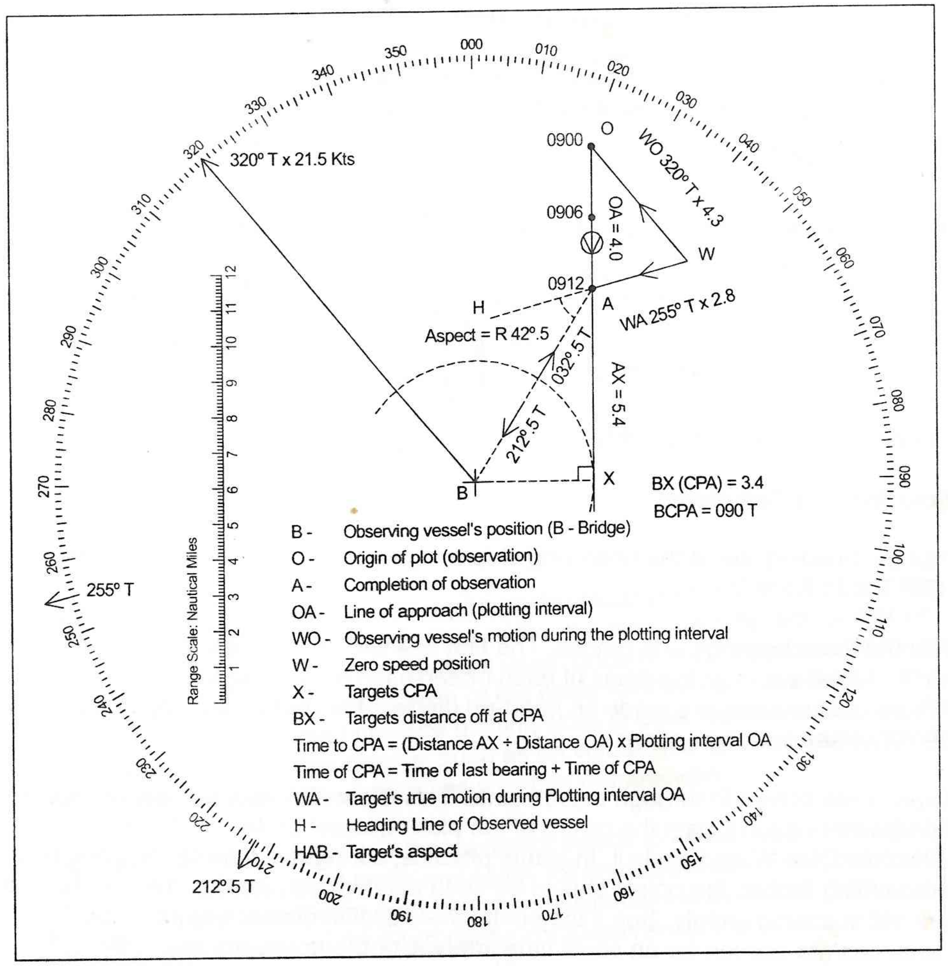

Figure 6.4 - Plot for use with Example 6.1

Time to CPA = (AX ÷ OA) x Plotting interval
= (5.4 ÷ 4.0) x 12 = 16.2 or 16 minutes
Time of CPA = 0912 + 0016 = 0928

Plot 'WO', usually referred to as 'way of own', in the direction of the observing ship's course, to join at 'O'. Mark a single arrow on this line in the direction of 'W' to 'O'. This is the motion line of 'own vessel' and equals:

WO = (Speed of observing ship ÷ 60 minutes) x plotting interval minutes
WO = (21.5 ÷ 60) x 12 = 4´.3.

During the actual plotting, 'WO' could be produced and plotted after the first plot has been marked in order to complete the vector triangle with minimum delay. Similarly, the plot should be labelled at an early stage, so that the rest of the bridge team can also understand the plot and interpret it.

After plotting 'WO', join 'W' to 'A' to produce line 'WA' which is the true track of the observed ship, usually referred to as 'way of another'. Mark a single arrow on this line in the direction 'W' to 'A'. The direction of 'WA' indicates the course or track of the observed vessel (255° T) and its length is indicative of the speed.

Speed of observed ship = (WA ÷ Plotting interval in minutes) x 60 minutes.
Speed = (2´.8 ÷ 12) x 60 = **14 Kts**

The final stage is the aspect. This is the relative bearing of the observing vessel from the target vessel, or angle on the bow of the target vessel. It is expressed from 0° to 180° Red or Green, depending on whether the observing vessel is on the Port or Starboard side of the target vessel. It is worked out as the difference between the Target's true course and the reciprocal of the last observed bearing.

Reciprocal of last observed bearing 032°.5 T is 212°.5 T
Aspect **= 255° T ~ 212°.5 T = Red 42°.5** (always obtain the shorter angle)

It can be worked out from the azimuth ring on the plotting sheet when course and bearings are marked during measurement.

6.2.2 Report

Most navigators believe that the report is based upon six items: Course, Speed, CPA, TCPA, Bearing of Closest Point of Approach (BCPA) and Aspect. Although these are generally the outcomes of the plot, they do not necessarily provide all pertinent information about the target. For a full report or analysis of the situation, the following items should be reported:

- Time of the report
- Target identifier or designator (where tracking a number of targets)
- Target's last observed true bearing
- Bearing Steady, Closing (drawing forward) or Opening (drawing aft)
- Target's last observed range
- Range Steady, Decreasing or Increasing
- Distance of the target's CPA
- Bearing of the target at CPA (true or relative)
- 'Time to' and 'Time of' the CPA
- Calculated true track/course of the target
- Calculated speed of the target
- Target's aspect
- Where applicable, general comments about overtaking or crossing.

For Example 6.1, the full report would read:

- 0912.
- Bearing 032°.5T
- Opening (drawing aft)
- Range 6′.4, decreasing
- CPA 3′.4, bearing 090°T in 16 minutes at 0928
- Course/track 255°T
- Speed 14 Kts
- Aspect Red 42°.5.

Information may be presented in tabular format, especially when plotting multiple targets.

6.2.3 Current or Tidal Stream / Other Relations Between 'O', 'A' and 'W'

The 4 plots in Figure 6.5 illustrate these issues:

Plot 1: The observing vessel is making way and the plot includes only the observations made during the plotting interval. There is no tidal stream. Note that for "A", 'O' and 'A' are at the same point.

Plot 2: There is no tidal stream and the observing vessel is making way. 'WO' is applied to both the targets "A" and "B". For "A", the 'WO' and 'WA' are in line, indicating that the target is moving on the same course and speed as the observing vessel. In case of "B", 'W' and 'A' fall on the same point, indicating a zero 'WA', which means that the target is stationary.

Plot 3: There is no tidal stream and the observing vessel is not making way, so 'WO' is zero. "A" is seen to be moving and "B" is stationary. For "B", 'O' and 'A' remain at the same point. Since 'WO' is zero, the relative approach of "A" is its true track as well. 'OA' = 'WA'.

Plot 4: The observing vessel is making way and the tidal stream is setting West. The plot of "A" is normal, while the distance between observing vessel and "B" is gradually increasing. "B" is known to be stationary. A fixed stationary object cannot be moving 'WA', so the vector 'AW' is the tidal stream, indicated by three arrow heads. The direction 'AW' is the set indicated as °T. The length of 'AW' is the drift experienced by the observing vessel during the plotting interval and is measured in nautical miles. It is used to work out the rate of tidal stream.

Rate of Tidal Stream = (Drift ÷ Plotting interval in minutes) x 60 minutes.

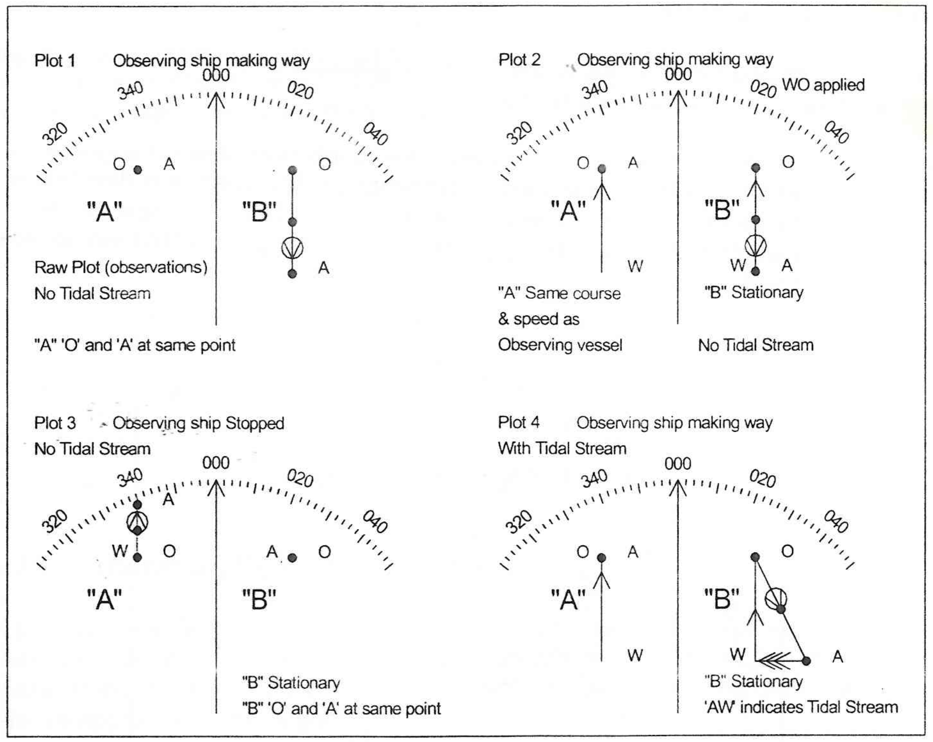

Figure 6.5 - Tidal Stream Plots

6.2.4 Alteration by Observed Vessel

The navigator needs to spot change in the direction and length of WA.

Example 6.2

A vessel steering 350°T at 15 knots, observes two targets on radar as follows:

0900	*A - 006°T*	*x 10′.4*	*B - 305°T*	*x 10′.6*
0910	*A - 017°T*	*x 8′.5*	*B - 303°T*	*x 8′.5*
0920	*A - 032.5°T*	*x 7′.1*	*B - 301°*	*x 6′.4*

If "A" is known to be a light vessel, compile a radar report for 0920.

Observation of "B" continued as follows:

0930	*292.5°T*	*x 5′.0*
0940	*259°T*	*x 3′.3*
0950	*211°T*	*x 3′.8*

What action has been taken by "B" between 0920 and 0930?

Solution and Comments

Follow the standard plotting procedure described earlier. For "A", 'AW' must indicate the tidal stream, as it is a stationary object.

For the observation of "B" from 0930 onwards, the labels have been changed as O1, W1 and A1. W1A1 should be examined for any change. The change in direction is an indicator of a change in the course and the direction W1A1 is the new course. Change in the length indicates a change of speed. Zero length of W1A1 would mean that the target had stopped.

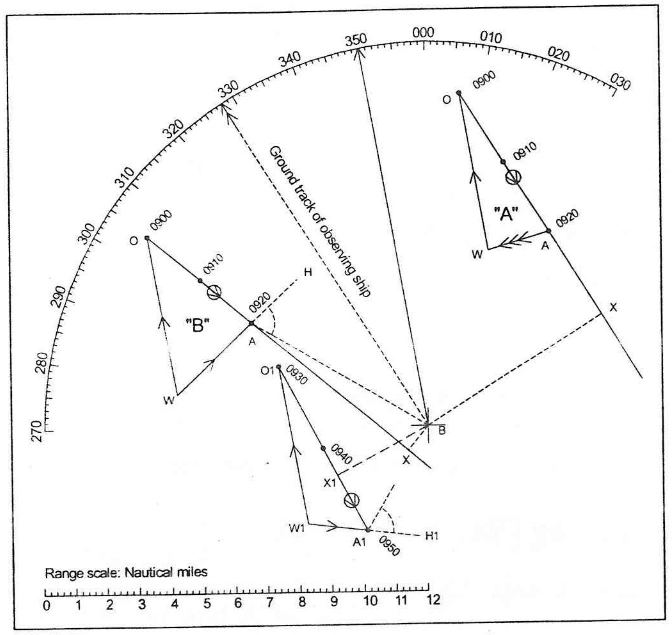

Figure 6.6 - Plot for Example 6.2

Report

	"A" at 0920	"B" at 0920	"B" at 0950
Bearing	032.5°T, opening	301°T, opening	211°T, opening
Range	7´.1, decreasing	6´.4, decreasing	3´.8, increasing
CPA	6´.4	1´	3´.2
BCPA	058°T	220°T	242°T
TCPA	12 minutes, 0932	30 minutes, 0950	Past 7 min, 0943
Course / Set	253°T	047°T	a/c 50° Stb, 097°T
Speed / Rate	5´.8	9.7 Kts	Reduced to 5.6 Kts
Aspect / Drift	1´.9	G 74°	R 66°

For "B" at 0950: in addition to new course/speed, all details have been added.

Note the 'past' TCPA and change of aspect to red. In figure 6.7, the 'ground' track of the observing vessel has been marked. It is the reciprocal of the relative plot of the fixed stationary object, i.e. 328°T at a speed of 15.4 Kts (from length of OA). It can be used to obtain the ground track of the target "B" and is illustrated in Figure 6.7.

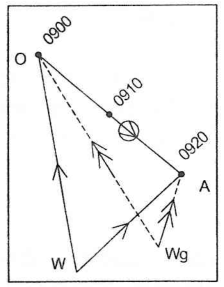

Figure 6.7 - Second Plot for Example 6.2

6.2.5 Alteration By Observing Vessel

In this case, the change of course is indicated by a new direction of 'WO' and a change of speed is indicated by a change of length of 'WO'. Where the observing vessel stops, 'WO' will be zero. In case of stopping, what would be the resulting relative approach of the target?

In most theoretical problems, the alteration is often instantaneously effective (Example 6.3). But in real life and in some problems, the alteration will have to allow for steadying on the new course or speed. This will involve application of head reach of the observing vessel during the manoeuvre.

6.2.6 Head Reach

In reality, when a vessel commences a manoeuvre, the intended course or speed is not effective at once. There is usually a time interval between the commencement of the manoeuvre and its completion. During this period, the direction and/or length of the relative approach is also changing. The distance travelled by a vessel in the direction of the initial motion during the manoeuvre is called 'Head Reach'. The exact value can be determined from the manoeuvring characteristics of the vessel, its speed, loading condition, depth of water, sea state and the helm angle used.

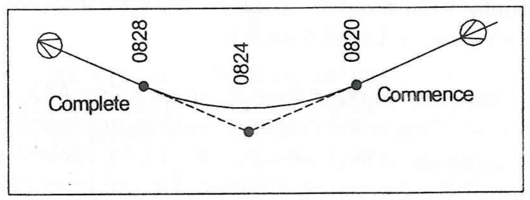

Figure 6.8 - Effective Time of Alteration

It may not be possible to include all the above information in an exam-style problem. Usually, head reach distance and the time taken for the manoeuvre would be included. For plotting purposes, the effective time to plot the new approach line of the manoeuvre is taken as the half way point. At that point of the manoeuvre, it is easier to plot a curved path (Example 6.6).

Another option is to plot the new approach from the position of the target vessel when the observing vessel has steadied on the new course/speed. In such cases, a bearing and distance of the target would be provided (Example 6.4).

Example 6.3

Using the information and initial observations in Example 6.2, and assuming any alterations are instantaneously effective, find a single alteration of course to be made by the observing vessel at 0930, in order to pass the vessel "B" at a distance of 3 miles. What effect will this alteration have on target "A"? Find the earliest time at which the observing vessel may resume its original course.

Solution and Comments

Draw the heading line of the observing vessel from the centre 'B' and label it 350°T @ 15 Kts. Plot the bearings and ranges of targets "A" and "B". Label the points and mark them with the times. Add the 'WO' line to complete the 'OAW' triangles. Extend the 'OA' lines for both. Mark the vectors with appropriate arrows.

The initial CPA of "B" was 1 mile on the port side. In order to pass it at 3 miles, the course should be altered to starboard. If visibility was restricted, avoid altering course to port for a vessel forward of the beam (Rule 19 d). Even when taking action in clear visibility, a power-driven vessel should avoid altering course to port for a power-driven vessel on its own port side (Rule 17 d).

Using a radius of 3 miles and centred on the sheet, describe an arc towards the port side of the observing vessel. Do NOT use a full circle to make a decision against a single target, as you could easily turn the wrong way. Only use a circle when the decision concerns a number of targets.

Since a course alteration is required for 0930, it is important to determine these points for both the targets. Measure the length of the 'OA' vector for both separately; this is the approach for 20 minutes. Use half of this distance to obtain the 0930 position for the targets. (If in another problem, the time interval is not exactly half, use the appropriate fraction). Label it as A1.

For target "B" (as 3 miles is required from it), draw a line A1X1 from A1 as a tangent to the arc drawn earlier. This is the required relative approach to pass "B" at 3 miles. With centre W and a radius of WO, describe an arc to starboard of WO. Draw a line parallel to A1X1 from A backwards to intersect the arc from W at the centre. Label the intersection point as O1. Join W to O1. OWO1 is the alteration of course required to pass "B" at 3 miles, i.e. 25°. The new course is 350°T + 25° = 015°T.

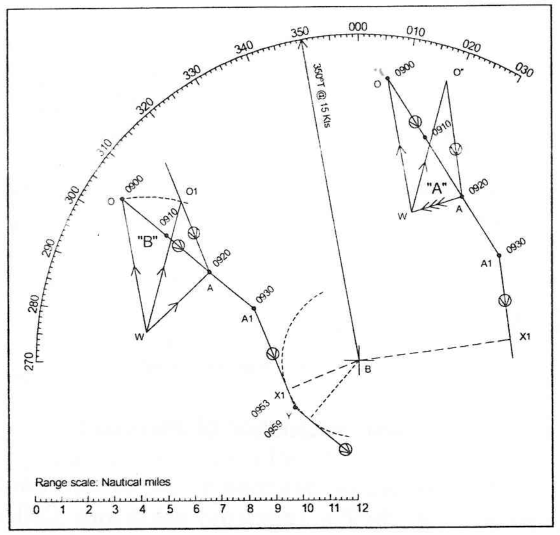

Figure 6.9 - Plot for use with Example 6.3

For effect on target "A", from point W, draw the new WO1 in direction 015°T at 15 kts. Join O1 to A and obtain the new relative approach line for target "A". Draw a line parallel to O1A from point A1 and run it past the CPA, X1.

For the time of course resumption, draw a line tangential (and parallel to the original OA) to the 3 mile arc, to intersect at Y the new line of relative approach A1X1. The point of intersection of these tow lines, Y, marks the earliest time that the observing vessel may resume its original course. The time can be determined:

Time interval = (A1Y ÷ O1A) x Plotting interval
= (4´ ÷ 2´.8) x 20 = 28.57 minutes = 29 minutes
Time of resumption = 1930 + 29 = **1959**

Example 6.4

A vessel steering 300°T at 18 Kts, observes a vessel on radar:

0800	*340°T*	*9´*
0810	*340°T*	*7´*
0820	*340°T*	*5´*

Compile a report for 0820. If the observing vessel alters course to 350°T, find the CPA information about the target if it was bearing 330°T x 3´.5 at 0830 when the observing vessel is steady on its new course.

If, in this situation, a decision was to be taken to reduce the speed instead, what speed should the observing vessel reduce to in order to get the same result?

Solution and Comments

Report:

- 0820
- Brg 340°T, steady
- Range 5´, decreasing
- CPA 0'.0
- BCPA 340°T
- TCPA in 25 minutes at 0845
- Course 259°T, Speed 11.7 Kts, Aspect Red 99°

After completion of basic plot and compilation of the report:

With W as centre and WO as radius, describe an arc to starboard of O. From W draw a line in the direction of 350°T to reach the arc drawn. Call this intersection point O1. Join O1 to A. This is the new relative approach of the target after observing that the vessel has altered course. O1'c' is so labelled to indicate its relation to course change.

Plot the bearing and range for 0830. From this point, draw a line parallel to O1A and run it past the CPA. Obtain the CPA information based on this new approach. CPA 2´.8; BCPA 292°.5T; TCPA in 9 minutes at 0839.

For a possible speed reduction, the point where the new O1A line intersects WO has been labelled O1's', to indicate its relation to speed change. Measure the length W to O1's'. This is the distance to be travelled in 20 minutes if speed is reduced. This distance can be converted into speed = **9.9 Kts.**

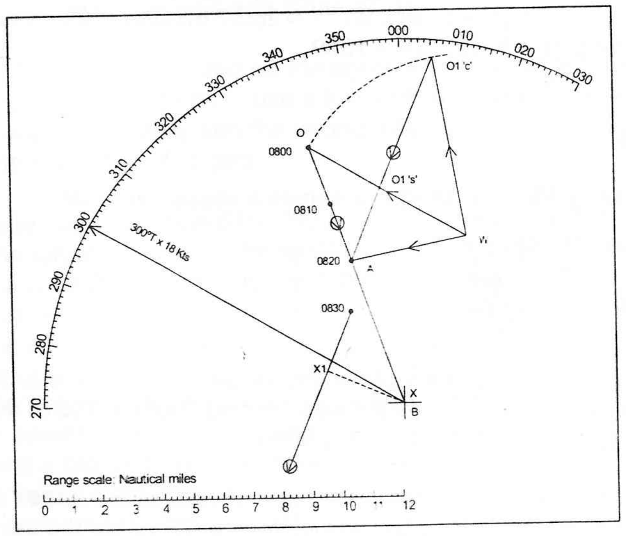

Figure 6.10 - Plot for Example 6.4

Example 6.5

A vessel steering 300°T x 18 Kts observed a vessel at 0800, 0810 and 0820 on a bearing of 340°T, ranges 9´, 7´ and 5´. The observing vessel's course was altered 50° to starboard at 0820 and it was steady on the new course at 0828. Find the new CPA information and the target's bearing and range at 0828.

Solution and Comments

The observing vessel experiences head reach between 0820 and 0828, giving 0824 as the effective time, i.e. 4 minutes after commencement. Using 4 minutes, a new Zero speed point should be determined and labelled W1, i.e. WO is for 20 minutes and W1O is for 24 minutes – method A. From W1 draw a line parallel to WA to intersect the OA line. Label this point A1. Using W1 as centre and W1O as radius, draw an arc to starboard of WO. From W1, draw a line in the direction 350°T. Where this line meets the arc is O1. Join O1 to A1 and extend it past the CPA. Using O1A1 as the approach speed, determine 0828 position: 322°.5T x 3´.3; CPA 2´.8; BCPA 292°.5T; TCPA 0832 (remember O1A1 is for 24 minutes).

Note: If a speed change was done, point O1's' should have been used. Having understood the principle, a simpler method can be used.

An alternate method, shown as B, is to determine A1 by marking the 0824 point A1 on the relative approach line. Produce O1A as normal and transfer it to the A1 point to obtain the bearing and range at 0828 and the CPA information. Both methods are shown for comparison.

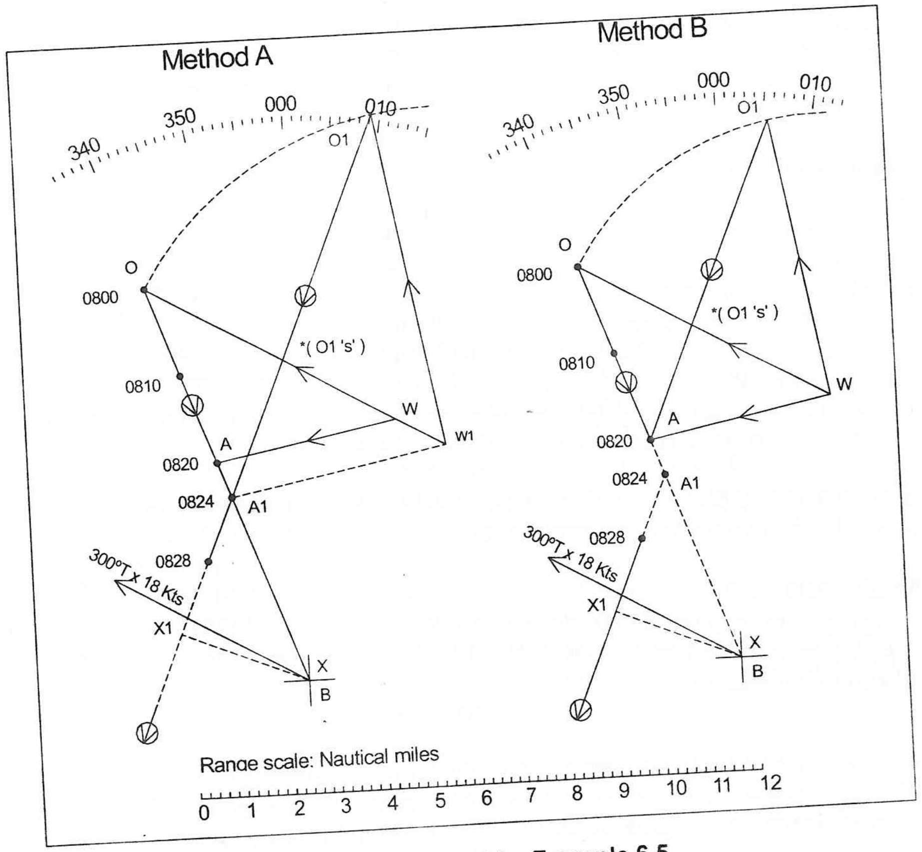

Figure 6.11 - Plot for Example 6.5

Example 6.6
A vessel on a course of 020°T at 10 Kts, observes a target on the radar:

0700	*300°T*	*10´.5*
0706	*301°T*	*8´.9*
0712	*302°T*	*7´.3*

If the observing vessel takes 10 minutes to stop and has a head reach of 1´.4, while maintaining the same heading, find the latest time at which to stop engines so that the target will pass 2´.5 ahead of the observing vessel.

Solution and Comments
Draw the heading line, 3 observations and complete the OAW triangle. On the heading line, mark X1. BX1 is 2´.5 (distance ahead the target should pass).

Method C: Through X1, draw a line parallel to WA and intersecting OA extended. From any point, Y, on this line, draw a line in the direction of the observing vessel's course and equal to head reach, YZ. If Z falls on the intersection of OA and YX1, call it point A1. Otherwise draw a line parallel to YX1 through Z and where it intersects the OA line should be the point A1. (Note Y1A1 and X1Z1 are 1´.4). A1 is the point

where the target should be when the observing vessel stops the engine. Work out the distance that the target will travel in 10 minutes and mark this distance from Y1 in the direction of target's course to A2. When the target reaches A2, the observing vessel would be stopped.

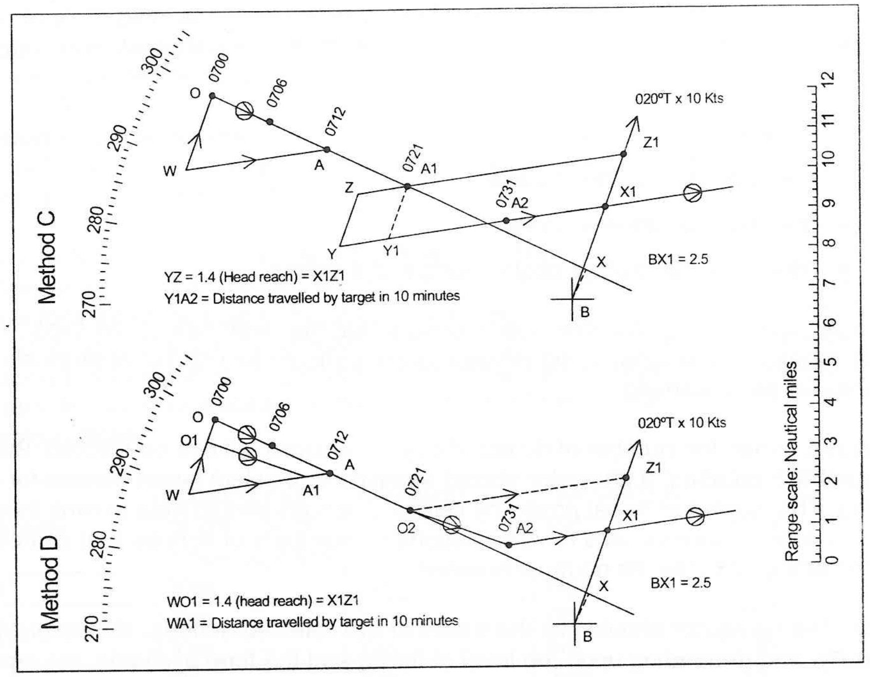

Figure 6.12 - Plot for Example 6.6

Method D: Having understood the principle, a simpler method can be used. Plot the heading line, the observations and complete the OAW triangle. From W, measure the head reach of 1´.4 in the direction of the observing vessel's heading to O1. Also, from W, measure the distance that the target would cover in 10 minutes and mark the point A1 on the WA line. Join O1A1 as the relative approach while the observing vessel is stopping.

Mark X1 at 2´.5 from the centre and mark Z1 at 1´.4 from X1. From Z1 draw a line parallel to the WA to intersect line OA extended. The point of intersection is O2. At O2, draw a line equal in length and parallel to O1A1 to obtain point A2. From A2, draw a line parallel to WA. This line should pass X1.

Using the relative approach OA, the time of stopping engines is worked out as 0721.

6.3 Collision Avoidance

The navigator can put radar to good use through the important stages in collision avoidance. It is the combination of the suitable set up of radar and the interaction with the navigator that makes it a valuable aid to navigation.

Detect: Here the influencing factors are:

- Range scale in use
- Pulse length
- Brilliance
- Gain
- Tuning
- Sea and Rain clutter controls
- Blind and Shadow sectors
- Headlands and other obstructions in the vicinity.

Optimum set up and skilful observation ensure that the radar detects as expected (within inherent limitations). Long range scanning should be used at appropriate intervals for early warning.

Prioritise: When the number of detected objects is small, all can be tracked. But as the number increases, a navigator should examine and select target echoes for plotting. The degree of threat posed by selected echoes should help to rank them for tracking. Most automatic aids have limitations on numbers of echoes that can be tracked at a given time, as do most humans

Track: The Navigator should plot the tracks of the selected echoes. Where plotting manually, and depending upon the level of threat and the time available, the report may have to be restricted to the nearest approach information only.
R O R: The relevant paragraphs of the ROR should be considered to decide on the responsibility between vessels and the avoiding action to be taken. Aspect and relative location of the target vessel would be required for ROR application. Justification for the choice of action is heavily dependent upon the mention and application of the relevant paragraphs of the Rules. The relevant application would be considered in the examples used.

Plan: The action to be taken by 'own vessel' should be planned and plotted. A trial manoeuvre may be used, where available, to plan the change required and to establish the appropriate time to take avoiding action. The effect of the intended action on other target echoes in the vicinity should also be examined.

Execute – Manoeuvre: The movements of all threatening echoes during the manoeuvre should be monitored carefully.

Monitor: Plotting should be resumed on completion of the manoeuvre. The vessel's return to her original status, or further avoiding action, should be considered, especially when in vicinity of other navigational hazards.

The following examples have been added to discuss the application of the ROR and some practical aspects that need to be considered while solving such problems.

Example 6.7
A vessel steering 045°T at 10 Kts, in conditions of restricted visibility, plots a number of echoes on radar on a 12 mile scale between1109 to 1127 hours. Analyse the situation as it exists at 1127. Also, determine a single alteration of course or speed at 1133, so as to pass at not less than 2 miles from all targets, assuming that any alteration is instantaneously effective.
(OA lines provided on the plot)

Solution and Comments
The OAW triangles should be completed and the OA lines extended to the CPA to analyse the situation at 1127.

Since it is restricted visibility, the requirements of Rule 19 apply. There are close-quarters situations with targets "A", "B" and "C" but none with "D". Since "A", "B" and "C" are forward of the beam, the observing vessel should avoid altering course to port. "D" is abaft the starboard beam. But, since there is no close-quarters with it, alteration towards it is not a concern unless the action engaged it in another close-quarters. In more complicated problems, a simple table can be used to list the possible options:

Targets	Existing risk of collision or close-quarters	Alteration to starboard	Alteration to port	Slow / Stop
"A"	Yes	Yes	No	Yes
"B"	Yes	Yes	No	Yes
"C"	Yes	Yes	No	Yes
"D"	No	Yes	Yes	No

Generally the action which is not in contravention (Yes for all targets) is the option. Additionally, aspects of Rule 8 should also be considered. These are the actions as per the rules

- Positive
- in ample time
- with due regard to good seamanship
- large enough to be readily apparent
- a succession of small alterations to be avoided, alteration of course being more effective
- not engaging in close-quarters with other vessels

Considering the above, an alteration of course to starboard would be the preferred choice, providing that the desired CPA is achievable.

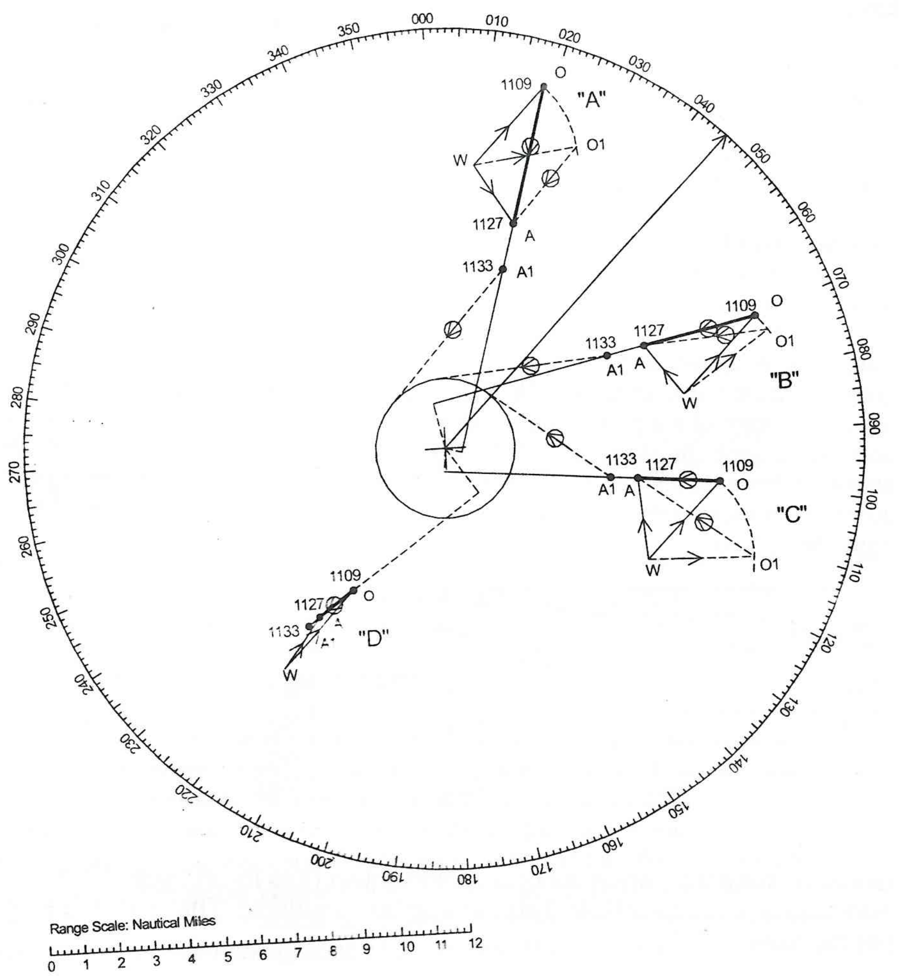

Figure 6.13 - Plot for Example 6.7

To determine the alteration, draw a circle of 2′ radius from the centre. Using the respective relative approach separately for each target, work out the point A1 where the targets would be at 1133, i.e. 6 minutes from 1127. From A1, draw tangents to the 2′ circle towards the port, as the course is to be altered to starboard. No tangent has been drawn for “D”.

Draw the new relative approach lines backwards at point A for each target. With W as centre and WO as radius, describe arcs to starboard of WO to cut the new approach lines. The intersection is point O1. Join W to O1 to determine the course alterations required. The courses worked out for “A”, “B” and “C” respectively are 083°T, 055.5°T and 092°T. The largest would be chosen. If an observing vessel steers this course, “A” and “B” would pass at a larger distance. If in doubt, always check. Similarly the effect of alteration on “D” should also be checked.

Report	“A”	“B”	“C”	“D”
Bearing	020°T closing slowly	076°T closing slowly	102°T opening slowly	220°T opening
Range	6′.7 decreasing	6′.4 decreasing	5′.6 decreasing	6′.1 increasing
CPA	0′.5	1′.3	0′.7	1′.6
BCPA	106°T	348°T	185°T	145.5°T
TCPA	30 m, at 1157	35 m, at 1202	44 m, at 1211	Past 80 m
Course	149°T	324°T	355.5°T	037.5°T
Speed	6.7 Kts	6 Kts	7.7 Kts	6 Kts
Aspect	G 51°	R 78°	R 73.5°	G 2.5°
Remarks	Crossing P - S	Crossing S - P	Crossing S - P	Overtaken by observing vessel

If the question required the report after altering course, then the chosen course would have to be applied to all targets to obtain the new relative approaches.

Example 6.8

A vessel navigating in conditions of restricted visibility within a lane of a traffic separation scheme, steering 225°T at 12 Kts, observes a number of echoes on radar on a 12 mile scale from 1530 to 1545 (OA lines provided on the plot, for target “B”, O and A are at the same point). After completing the plot, analyse the situation as it exists at 1545.

The Master decides to disengage from the present situation. Determine the alteration of course and/or speed required at 1550 to clear the situation, assuming any alteration is instantaneously effective. State the reasons for the action taken by the observing vessel.

Solution and Comments

The OAW triangles should be completed and OA lines extended to CPA to analyse the situation at 1545.

Report	“A”	“B”	“C”	“D”	“E”
Bearing	273°T opening	315°T steady	027°T closing	070°T steady	222°T closing
Range	4′.2 decreasing	1′.6 steady	2′.6 decreasing	4′.2 decreasing	6′.1 decreasing
CPA	3′.1	1′.6	0′.4	0	1′.2
BCPA	315°T	315°T	305°T	070°T	300°T
TCPA	14m, 1559	Now	26m, 1611	57m, 1642	28m, 1613
Course	-	225°T	221.5°T	231.5°T	318°T
Speed	0	12 Kts	18.2 Kts	16 Kts	3.2 Kts
Aspect	-	R 90°	R 14.5°	G 18.5°	G 84°
Remarks	Stopped, at anchor, or fixed object	On same course and speed	Overtaking and converging	Overtaking and converging	Crossing TSS at right angle

Since the vessel is in a TSS, in addition to Rules 8 and 19, the requirements of Rule 10 also need to be considered. The vessel should proceed in the general direction of traffic flow for that lane. This implies that slowing down may be considered a viable option in similar situations only if it results in passing at a safe distance. In this example, slowing down is a poor option. Similarly, alteration to starboard is a poor choice due to the presence of "B" and C". Alteration to port has been chosen in departure from Rule 19(d), as "D" has a TCPA in 57 minutes, and the action satisfies the considerations of Rule 8. The considerations and reasons have been listed on the plot. A table could also be prepared to list the possible choices. "C" and "D" will pass at 1´.8 from the observing vessel and "E" at 4´.2.

It must be noted that the example is not used to suggest or recommend departure from the rules, but to instil in the navigators mind the ability to consider all options to ensure the safety of the vessel.

With regard to plotting, since the example did not require a minimum distance for passing, a single action has been used for all vessels. The course alteration has been worked out mentally just by observation of the targets and the threat they pose. This is a skill that the navigator should develop with knowledge and experience. Additionally, the working for O1 points for "A" and "B" has not been shown in order to keep the plot clear (the new relative approach lines have been plotted anyway). This is due to the prioritising of the other three targets for tracking, as they pose the main threat. Exam solutions would require all working.

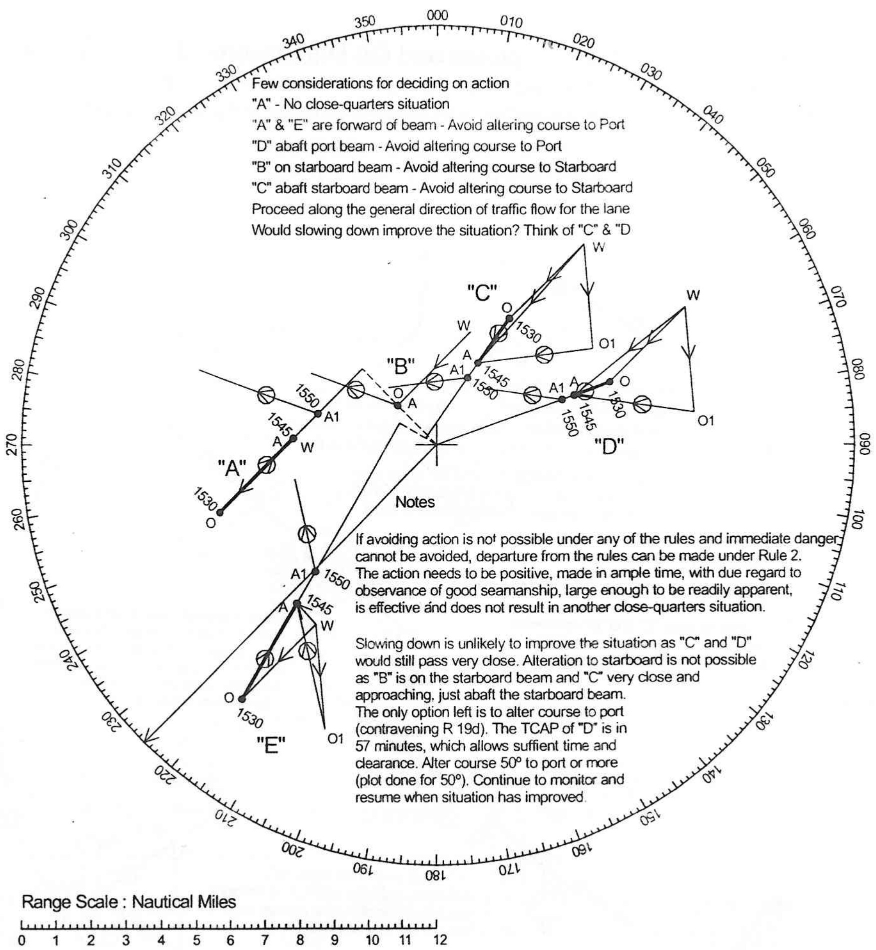

Figure 6.14 - Plot for Example 6.8

Example 6.9

Whilst making landfall, the observing vessel encounters restricted visibility and is proceeding on a course of 060°T at 10 Kts. A number of targets are observed and tracked on radar from 0612 to 0630 (OA lines provided). Target "D" is a small island.

- *Analyse the situation as it exists at 0630 and determine set and drift.*
- *Assuming that any alteration is instantaneously effective, determine the course of action at 0639 ensuring that none of the targets has a CPA of less than 1´.5*
- *Determine the new CPA of "D" after action has been taken.*
- *Comment on the situation after 0639 and, with reasons, suggest further action if any is required.*

Solution and Comments

The OAW triangles should be completed and OA lines extended to the CPA to analyse the situation at 0630. In addition to collision avoidance, general navigational safety also needs to be considered as the vessel is in vicinity of the coast and is being set towards it.

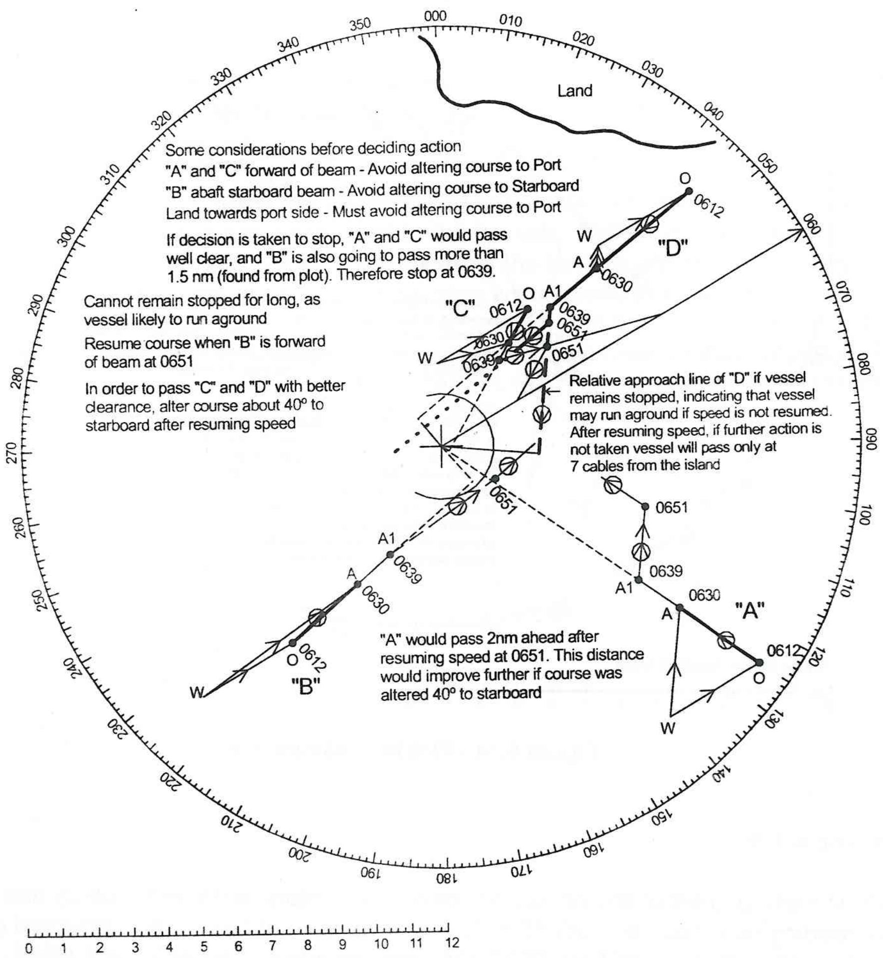

Figure 6.15 - Plot for Example 6.9

From analysis of the reasons listed on the plot, the observing vessel should stop engines at 0639 in order to pass all targets at more than 1´.5.

After stopping, "D" would have a CPA of 2´.8, BCPA 095°T, TCPA in 114 minutes at 0824.

After stopping, monitoring should continue. When "B" is forward of the beam, after 0651, resume speed. At this stage, "A" will cross 2´ ahead, "B" will continue well clear, "C" is going to converge and pass ahead at 2´.5 after 29 minutes at 0720.

Whereas "D" will pass at 0´.7 only. In order to increase the distance from the island "D", the observing vessel should alter course to starboard by about 40°.
For clarity, the section around "C" and "D" has been blown up below.

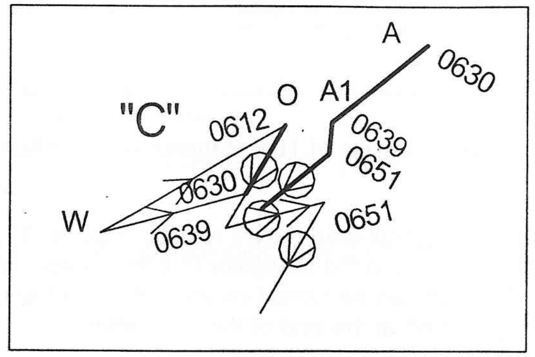

Figure 6.16 - Second plot for Example 6.9

Report	"A"	"B"	"C"	"D"
Bearing	125°T steady	212°T closing	034°T closing	042°T opening
Range	8´.2 decreasing	4´.6 decreasing	3´.5 decreasing	6´.7 decreasing
CPA	0´.0	1´.3	0´.2	1´.0
BCPA	125°T	139°T	120°T	321°T
TCPA	53 m, at 0723	32 m, at 0702	57 m, at 0727	35 m, at 0705
Course	005°.5T	053°T	075°T	Set 005°T
Speed	10.4 Kts	18.3 Kts	7.1 Kts	Rate 2.2 Kts
Aspect	R 60°.5	R 19°	G 139°	Drift 0´.7
Remarks	Crossing	Overtaking & converging	Being overtaken	Vessel setting towards land

6.3.1 Use of Trial Manoeuvre

When using ARPA, the change of course or speed required for passing safely from the other ships can be determined by using the trial manoeuvre function. Different makes of ARPA may have different styles to show the results. The inputs required are:

- Planned course change (xx° port or starboard)
- Planned speed change
- Time delay (time after which action would be taken)

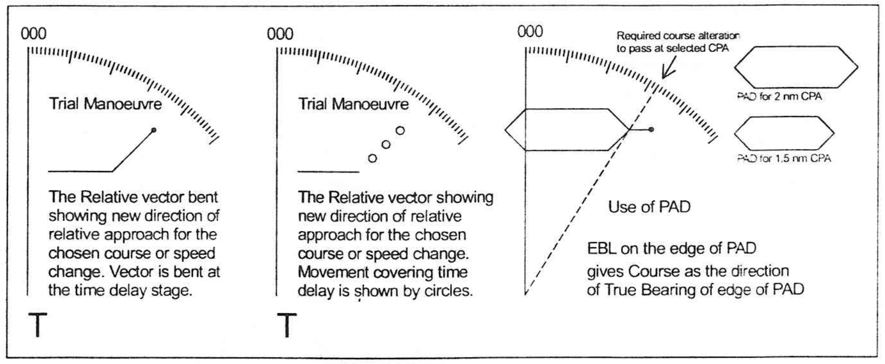

Figure 6.17 - Use of Trial Manoeuvre and PADs

While the ARPA is displaying trial manoeuvre results, a letter "T" or word "TRIAL" would be on the PPI, indicating to the navigator that this is not reality. On most units, the trial manoeuvre function can be turned on and off. On others, the trial manoeuvre would only turn off at the end of the time delay.

The Required course alteration could be determined for a single ship using EBL on ARPAs with PAD (predicted area of danger). The EBL should be aligned with the desired edge of the PAD for the side to pass (Figure 6.17). The true bearing obtained gives the course required for passing the other ship at the desired safe distance, i.e., CPA. The size of PAD can be increased or decreased with the CPA selection. The edges of a PAD indicate the CPA selected.

6.4 Common Plotting Errors And Penalties (UK Examining Board)

During the UK Exams, main errors in initial plotting of target echoes and/or the incorrect plotting of the initial course and distance run of 'own vessel', thereby making the target vessel's initial courses and speed wrong, are treated as serious errors in principle (P) – 50% marks deducted

The following are clerical errors (C) – 10% marks deducted:

- Times not given on target echoes positions
- Recognised arrows not used on vector triangle
- Recognised lettering not used on vector triangle

The above are very minor omissions but are costly during exams. Similarly minor errors in calculation may be treated as C.

The following are clerical/principle errors (CP) – 30% marks deducted:

- Wrong use of scale, especially when trying to enlarge the area of plot
- Using both sides of the plotting sheet with incorrect scale

The following may be marked as CP or P depending upon the plotting approach demonstrated and how serious the resulting error is:

- Joining individual echoes of a target clearly on a steady course, which gives small alterations of course for the target
- Unity or imprecise drawing
- Not showing recognised construction for predicted alterations of course/speed of own vessel
- Not showing recognised construction for alterations of course/speed of target vessel(s)

Errors that indicate a lack of understanding may be treated more seriously.

6.5 Use For Navigation

Radar is a very effective aid to navigation as it provides the range and bearings of objects detected within the range scale. Apart from plotting position, it can be used effectively for continuously monitoring the vessel's progress in coastal waters.

6.5.1 Parallel Indexing

As a vessel moves on its intended track, fixed objects in the vicinity appear to be moving in the reciprocal direction of its motion (ground track). This technique provides the radar observer with real-time, instant information on the ship's lateral position, relative to the planned track. The information is essential in restricted waters with a lot of traffic congestion as frequent course changes that need to be made can only be done if the vessel is operating within its planned margins of safety. For these reasons it is particularly useful during restricted visibility. Provided that the passage plan has been prepared diligently, parallel indexing provides confidence to the bridge team about continued progress of the vessel in safe waters. At least two methods can be used for PI.

6.5.1.1 "Cross Index Range" (CIR) Method – Straight Index Line.

This is based upon the lateral distance of the planned track from a selected object. It can be employed at all times when using PI. Having identified all of the hazards, marked the limiting danger lines and tracks, a suitable charted object should be selected. A line parallel to the planned track should be drawn on the inner edge of the selected object and not through it. Maximum "margins of safety" (MOS) should be marked either side, or the side with off-lying dangers. Perpendicular distance should be measured from the track to this line. This distance is the CIR. Distances should also be measured for the MOS.

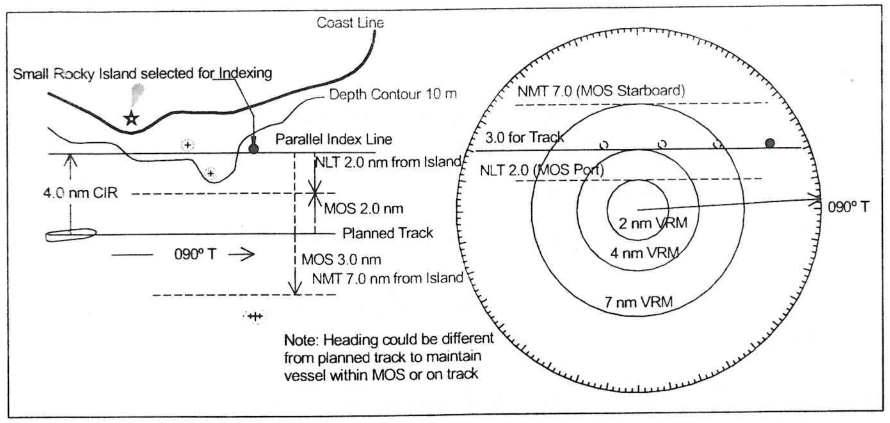

Figure 6.18 - Planning for PI

In Figure 6.18, CIR is 4′.0, MOS port 2′.0 and MOS starboard 3′.0 from track. MOS port is 2′.0 (4 – 2) and MOS starboard is 7′.0 (3 + 4) from the Index line. The MOS port distance is treated as the "not less than" (NLT) distance from the danger and MOS starboard as the "not more than" (NMT) distance from the index line.

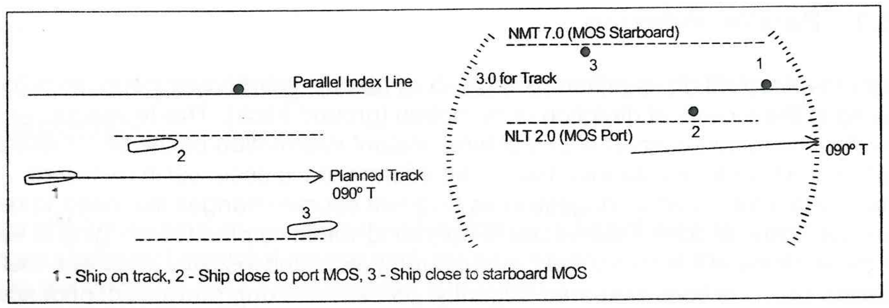

Figure 6.19 - 3 Positions of Ship and Relative Radar

The three lines should be marked on the radar screen as index line and MOS lines, either electronically or on the plotter using VRM and cursor. Most modern radars have the capability of producing index lines directly without the use of VRM. To proceed safely, the selected object should remain on the track index line and never outside the NLT and NMT lines. VRM can also be set to monitor.

This method can also be used for course alterations. The CIR for the present and the next track should be measured off of a selected object. It is preferable to use a single object in this case. The index lines and, if required, the MOS lines, should be marked.

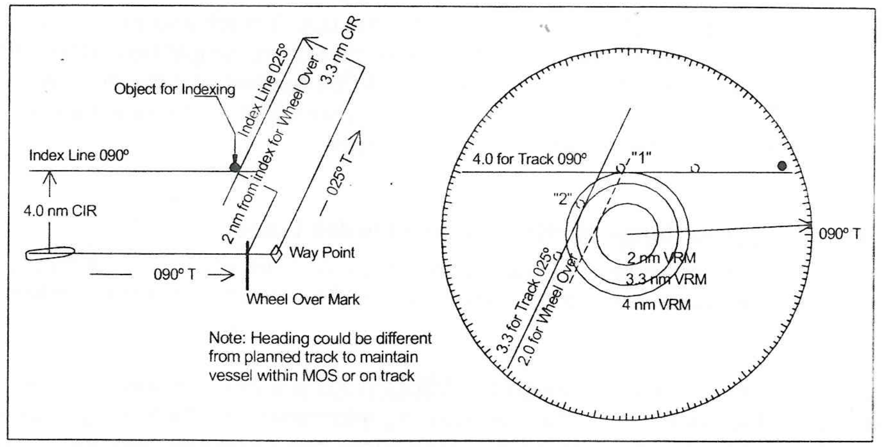

Figure 6.20 - Planning for Course Alteration

For wheel over, measure the perpendicular distance between the wheel over mark and the next track (025°T) index (2′.0). Mark this on the radar. When the echo of the selected object reaches the wheel over index (point "1"), planned helm should be applied. On completion of the turn the vessel would be on the planned track, with the echo on the next track index (point "2").

6.5.1.2 Bearing and Range Method – Straight Index Lines

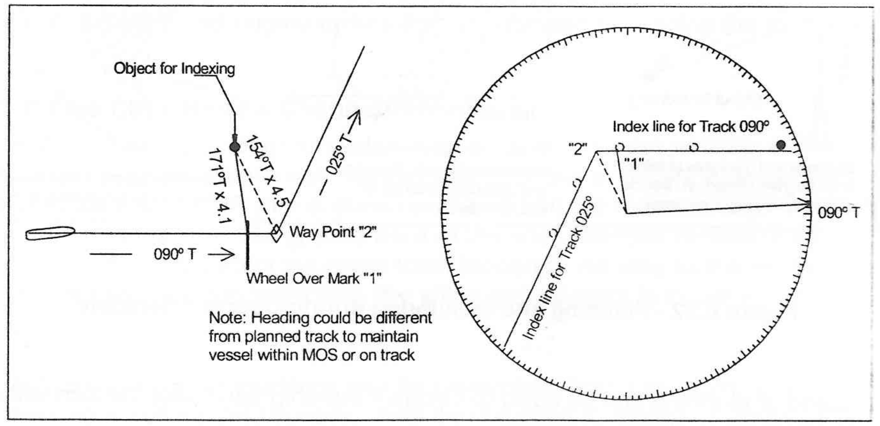

Figure 6.21 - Bearing and Range Method

The scenario illustrated in Figure 6.21 has been used here. The "bearing and range" from the way point and the wheel over mark should be determined.

The range and bearing from the way point should be marked on the radar display in reverse. From this point ("2"), the index lines for the 090°T track and the reciprocal of 025°T should be marked. Initially the echo of selected object would be on the 090° index. As it reaches point "1", planned helm should be applied and the echo would steady up on the 025° index line. once the ship has steadied on the new heading. Course corrections may be required to maintain track.

6.5.1.3 Bearing and Range Method – Curved Index Lines

Turns within narrow or congested waters are critical and require good monitoring, which can also be achieved through PI techniques. This can be performed in two ways.

Where it is just an alteration between two tracks (Figure 6.22), the curve can be plotted first on the chart, using the manoeuvring information on the turning circles of the ship. A suitable object on the inside of the curve should be selected and ranges and bearings for different changes of heading from this object should be plotted. This information can then be transferred to the radar.

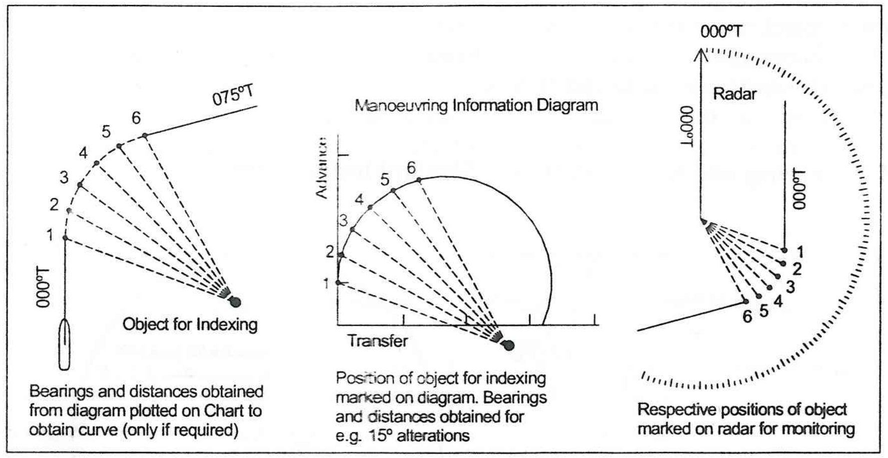

Figure 6.22 - Planning and Monitoring during Course Alteration

This method of planning can be used to decide if the ship can make the turn without, for example, the assistance of tug(s).

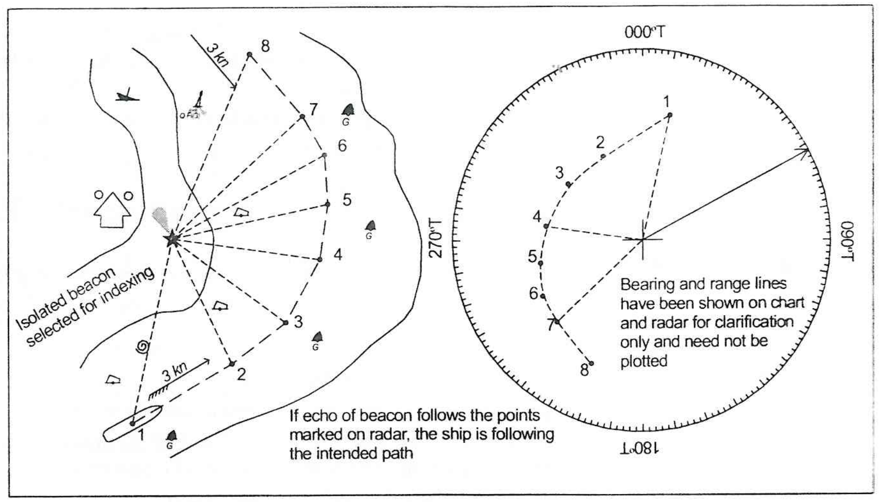

Figure 6.23 - Bearing and Range Within a Narrow Channel

Alternately, the ship may be navigating through a narrow channel, making frequent course changes and executing curves of differing curvature, using different helm (Figure 6.23). In such cases, the intended position of ship within the channel should be marked, which, depending upon the channel, may take the form of a curve. On this curve, points at about 1 to 3 cables should be selected. Bearings and ranges of these points from an object conveniently fixed for indexing should be measured for transfer to radar. This object should be on or close to the centre of curvature of the curve. A table can be prepared that lists the range and bearing of the selected object, along with the helm and engine orders that are planned to execute the manoeuvre.

6.5.1.4 Zero CIR – Narrow Channel Technique

This method makes use of ground stabilised input and relative vectors, and is used in areas where channels are well marked with beacons or buoys. A single line parallel to the track of the ship is drawn or marked on the radar, through the point of origin, to act as the intended ground track of the ship. Relative vectors or trails should be selected to detect the cross track tendency. As long as the relative vectors or trails are parallel to the index line, the ships ground track is in line with the intended track.

The distance of channel markings can be determined from the origin, indicating the way the ship is setting. Additionally, VRM can be used to monitor distances from the channel markings. Actual headings may be different to make adjustments. VRM can also be used with the CIR method to check safe distances if the bridge team have decided not to use the NLT or NMT lines.

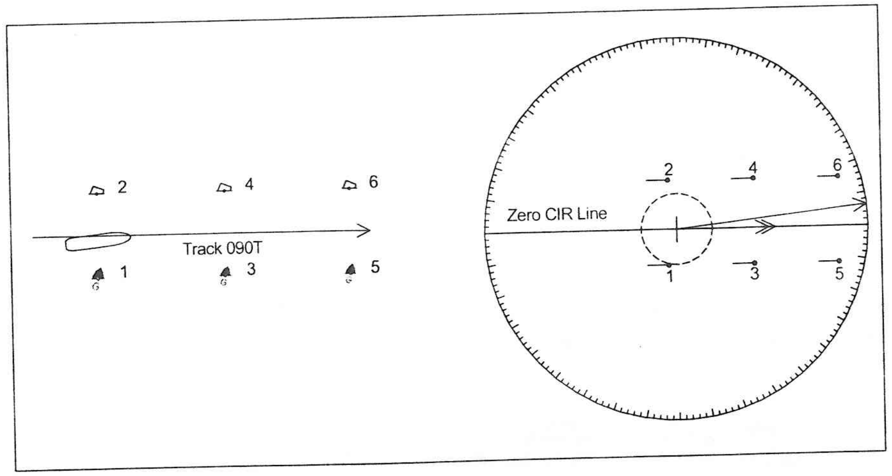

Figure 6.24 - Zero CIR Within a Narrow Channel

6.5.2 Use Of Nav Lines

Most radar and ARPA units include the added functions of Mapping and/or Nav-Lines. These functions can be used for channel keeping or track keeping within margin of safety in congested waters. The maps or nav-lines can be created electronically. The operator selects a fixed object to ground reference the ARPA. The monitoring is performed conveniently and the bridge team is able to plan for any course correction or course change.

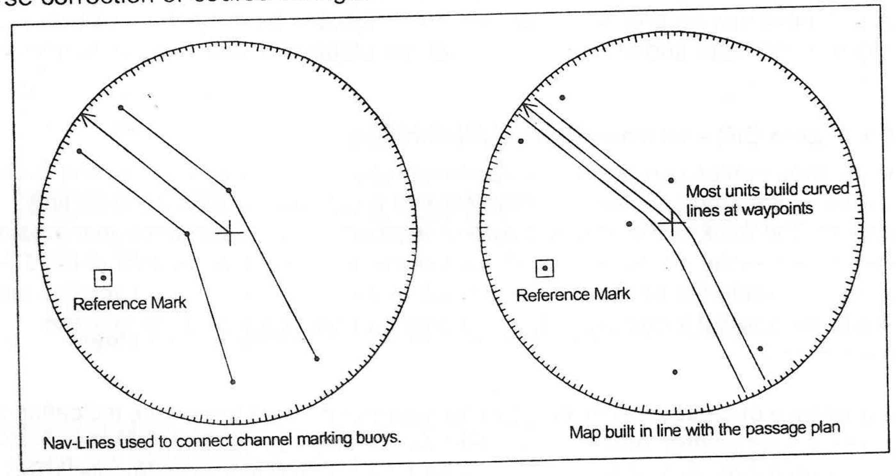

Figure 6.25 - Use of Nav-Lines and Mapping

The object selected for reference should, by preference, be an isolated fixed object, e.g., a very small island, a beacon in the water, etc. Where a selected object carries a RACON, it is possible that the ARPA might track the RACON signature of the reference target. In the event of this happening, the nav-lines could move off the

channel reference and the bridge team should choose a different navigational aid for reference and redraw the nav-lines.

On some units it is possible to fix the position of nav-lines with respect to the ship. These lines can then be used in a traditional parallel indexing manner.

6.5.3 Precautions With Parallel Indexing

To effectively use parallel indexing for monitoring the ship's progress, after carefully preparing a plan precautions must be observed :

- The radar should be set up properly, presenting a picture of good quality and displaying the required echoes effectively. Control settings should allow for the optimum picture. Suppressing controls, like rain and sea control, should be minimised and they should be turned off when not required. Time base must be accurately centred
- The radar should be checked for range, bearing, heading marker and picture rotate accuracy
- The compass error needs to be known and the heading marker carefully aligned
- The choice of navigational set up depends upon the area of operation. North-up relative motion would be preferable in coastal waters, whereas North-up true motion would be a good choice in narrows
- The selected object should produce good radar echo. Preferred choices would be steep sided, radar conspicuous marks, e.g., headlands, isolated rocks, isolated beacons and navigational marks with RACON. Objects should be selected on both sides of ship's track to minimise errors in range plotting, mark identification and radar linearity errors. Low lying objects and coast line should not be used, e.g., sand dunes, tidal low coast lines, etc. Objects should be correctly identified
- The selected object should not be obscured from the radar scanner by the presence of other objects
- Consideration should be given to radar blind and shadow sectors and the length of time the selected object is likely to remain within these sectors
- Range scale is an important factor, particularly when it needs to be changed. On older conventional radars with reflection plotters, any change of range scale during parallel indexing would cause major work load for the navigator. Most modern radars allow index lines to shift with change of range scale. However, not all modern radars perform in such a way. Navigators need to know the limitations and peculiarities of their own radars. Check the VRM and range rings
- Too many index lines clutter the display. At any given time, not more than two sets should be on the radar display, one currently in use and the other for use immediately after the present set
- Parallel indexing does not relieve the navigator of the responsibility to plot positions at the predetermined intervals.

6.5.4 Landfall

Radar should be used with caution when used for landfall. Under normal conditions, radar pulses travel in a straight line. This implies that the radar can detect objects far beyond its horizon, provided that the object is at an elevation that can be negotiated by the radar. The maximum range that radar can detect to depends upon the height of scanner and the height of the object. The maximum range "R" can be determined by the following formula:

$R = 2.23 (\sqrt{h} + \sqrt{H})$ sea miles (where heights are in metres)
$R = 1.23 (\sqrt{h} + \sqrt{H})$ sea miles (where heights are in feet)

A ship fitted with radar scanner 35 m above sea level can detect a 450 m high peak at a range of 60.5 miles.

The formulae can be transposed to determine the height of the object "H" that can be detected at a given range.

$H = 0.201 (R - 2.23 \sqrt{h})^2$ (heights in metres)
$H = 0.661 (R - 1.23 \sqrt{h})^2$ (heights in feet)

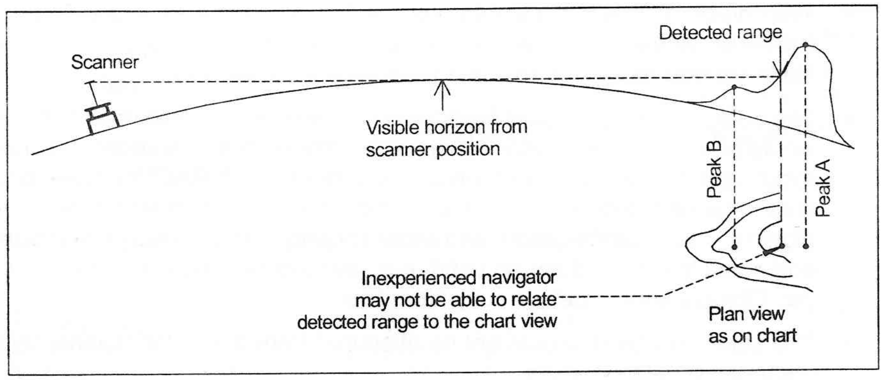

Figure 6.26 - Visible Radar Horizon

If the height of a radar scanner is 35 metres and it generates an echo at 44 miles, the height of the object generating the echo is 190.8 m.

When plotting a fix at longer ranges using radar, the ranges are unlikely to cut at the actual position of the ship and give only a general indication of the area where the ship is. In such cases, radar bearings of any peaks that have been detected should also be plotted.

It is important to remember that radar will not necessarily detect an object with poor radar reflection properties even when it is within the detection range. Similarly maximum detection range, in addition to heights, is dependant upon the power and performance of the radar, reflective properties of the object, and the atmospheric and sea conditions

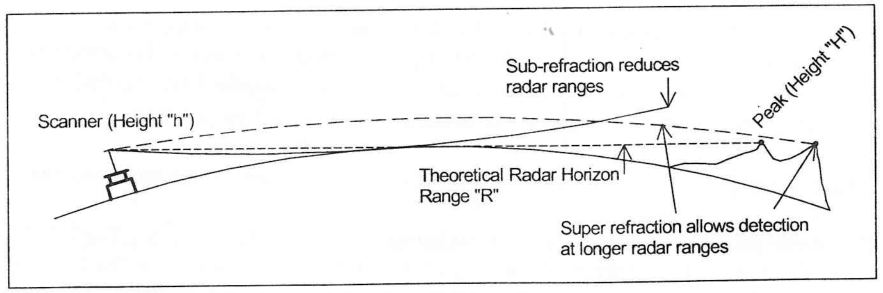

Figure 6.27 - Theoretical Radar Horizon

6.5.5 Position Fixing

The best radar fix can be obtained through two or more ranges. Ranges ahead and astern should be measured first, followed by beam, as the distances ahead and astern will change more rapidly than those abeam. This keeps measurement time delay error to a minimum. Range should be measured from the near side of the displayed echo or RACON, i.e., the variable range marker VRM should not overlap the displayed echo. There may be other errors in range.

These may be index errors, which can be caused by time delays or the radar set. Where known, the range index error should be available to the navigator for application to ranges measured. Some design factors like oscillator frequency, linearity in radar range rings and non-synchronisation between VRM and fixed rings cause errors in older designs. Range setting should be optimum, e.g., the range of an object at 2´.5 should be measured at 3´ scale and not 6´. Reflecting the properties of different objects and the height of tide may cause errors in range.

Bearing accuracy on radar is affected by horizontal beam width, using a longer scale than necessary, heading marker errors, aligning of radar antenna, antenna motor, gyro or transmitting compass error and squint (experienced in scanners fed from the end, the error occurs due to change in frequency of oscillator).

Older radars may have centring and parallax errors associated with the cursor. Bearing should be taken through the middle of an isolated object, as well as RACON, to eliminate beam width error. When taking bearing of a headland, it should be from the edge and a half beam-width should be applied.

6.6 Radar Detection and Interpretation

The ability of navigators to interpret the displayed picture on radar depends upon their understanding of the characteristics of radar propagation, capabilities of the radar, the reflecting properties of different radar targets, and the navigator's ability to analyse the chart and compare the displayed picture to it.

6.6.1 Characteristics of Propagation

The pulses of energy that form the radar beam show as lobe-shaped patterns of radiation. The energy is concentrated along the axis of the beam. To enhance detection and improve accuracy, the radar beam has specified horizontal and vertical beam widths, which are referenced to arbitrary selected power limits.

The main lobe of the radar beam is composed of a number of separate lobes.

As the wave passes an obstruction, it experiences bending. This is called diffraction and causes some illumination of the region behind an obstruction or target. The radar beam of lower frequency radar usually illuminates more of the shadow region behind an obstruction than radar of a higher frequency.

Radar beam energy also experiences absorption and scattering as it passes through the atmosphere. This phenomenon is called attenuation and it causes a decrease in echo strength. It is greater at higher frequencies.

Radio/radar waves usually travel in line of sight. This implies that the detection range of radar is dependent on power output and height ($r = 2.23\sqrt{h}$ [m]). Atmospheric density gradients bend radar rays as they travel to and from a target. This is called 'refraction' and it has an effect on detection range.

Super-refraction is a phenomenon where rays are bent downwards more than normal, causing longer radar ranges. It occurs when air, having flown over a warm land mass, moves over a relatively cold sea. This mostly happens in temperate and tropical zones. A moderate degree of super-refraction is present over the sea.

Sub-refraction is a phenomenon where the radar radiation does not bend down enough, or even bends upwards, causing shorter radar ranges. It may occur at high latitudes when a cold air mass flows over a warmer surface, e.g. wind blowing over open water after having passed over ice. Detection ranges may be reduced to the point where contacts visible to the eye are not displayed on the radar.

6.6.2 Reflective Properties

The reflected radar pulses depend upon how many pulses are absorbed by the substance that they strike on. Common substances, in descending order of reflection would be metal, stone, water, clay, wood or vegetation (trees).

The shape and aspect of the object are also important. Figure 6.28 illustrates the basics of reflection from various surfaces and different aspects. Size is also an influencing factor, a larger ship produces a stronger echo than a small one at the same distance.

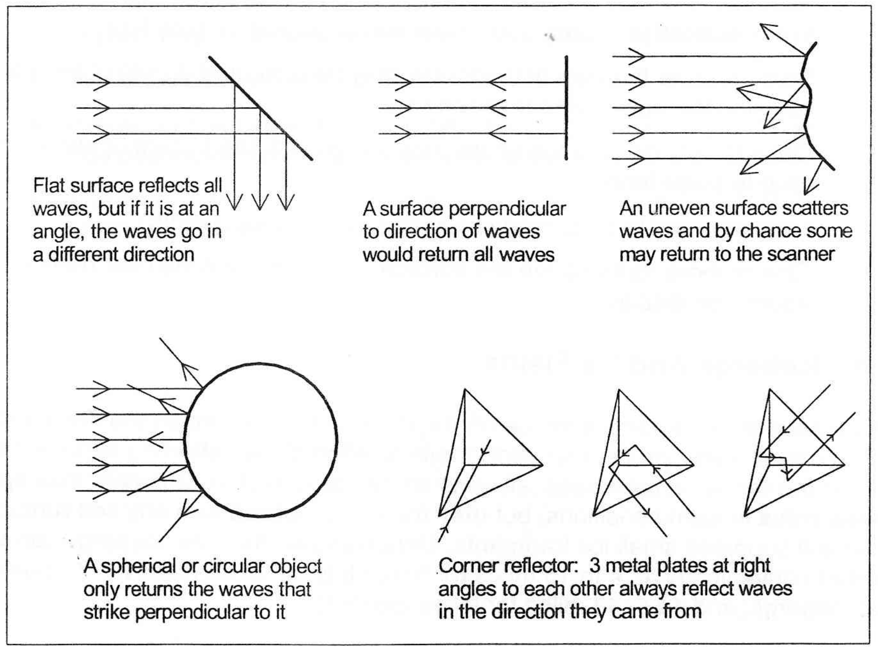

Figure 6.28 - Reflective Properties

6.6.3 Interpretation

Landmasses are generally recognisable by the steady brilliance of the relatively large areas displayed on the radar screen. The land would generally match the chart at a smaller scale, but all the features may not be easily recognisable. Some distortion may result due to beam width and pulse length. The following points need to be considered for the respective features:

- Lagoons and inland lakes would usually appear as blank areas
- Long chains of islands or coral atolls may produce long lines of echoes, especially when the radar beam is perpendicular to the line of islands
- Low islands usually produce small echoes
- Land rising in a gradual manner produces a steadily glowing area on the display
- Small hills and valleys produce blotchy signals (radar shadow effects)
- Smooth clear beaches and sand pits normally do not appear on the display beyond about 2 miles
- Sand dunes covered with vegetation, that are well back of a low smooth beach, produce an apparent line on the display that matches the dunes rather than the actual shore line

- Marshes and mud flats reflect radar pulses a little better than a sand pit. Weak echoes produced during low tide disappear at high tide
- Some sizable features of landmass may be obscured due to other features blocking the pulses (radar shadow)
- Objects very close to the shore may merge with the picture of shore line (due to pulse length)
- Land appears to be spread in bearing (due to beam width)
- One or more rocks above the surface or waves breaking over reefs may appear on display.

6.6.4 Icebergs And Ice Fields

The absence of any returns from ice on the display does not mean the non-existence of ice. Echoes produced depend upon the inclination of the reflecting surface, the size and the range. In calm seas, all sorts should be detected. Growlers may appear at a few miles in calm conditions, but may remain unnoticed with any sea running. Clutter will suppress small ice fragments. Depending on the size, icebergs can be detected conveniently at: 4 to 15 miles for bergy bits; 10 to 40 miles for medium sized icebergs; and 14 to 48 miles for large icebergs.

Concentrated hummocked ice can be detected at about 3 miles. Smooth ice fields may be distinguished from the open sea when some sea is running, as they do not produce any return (as opposed to when sea is running due to wind).

Ridges show clearly and shadow areas behind ridges can be mistaken for open water. Large floes in the midst of brash ice will show on radar. A Lead through static ice will not show unless it is at least 0.25 miles wide.

Areas of open water and smooth floes will look very similar. In ice, the filed edge of a smooth floe is prominent, which is not the case for open water.

6.6.5 Unwanted Echoes

In order to avoid confusion and unnecessary alterations, the navigator should be able to recognise the various unwanted echoes that may appear on the radar display.

6.6.5.1 Indirect Echoes

Indirect echoes are caused by a reflection of the main lobe of a radar beam from a part of the ship's structure, such as the funnel or masts,. When it occurs, the echo returns from an actual target through the indirect radar wave path.

The main characteristics by which indirect echoes are identified are as follows.

- Indirect echoes appear on the same range as direct echoes
- Indirect echoes usually occur in shadow sectors
- Indirect echoes appear on substantially constant bearing, even when the true bearing of target changes significantly
- The shapes of indirect echoes may indicate they are not direct. Movement of indirect echoes is usually abnormal.

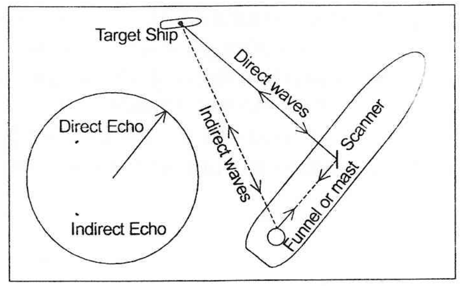

Figure 6.29 - Indirect Echo

6.6.5.2 Side-lobe Effects

A series of echoes is produced on each side of the main lobe echo at the same range as the latter, in semicircles or even full circles. This effect only occurs at shorter ranges, due to the low energy of side lobes, and can be eliminated or minimised by gain or anti-clutter controls. Slotted wave guide arrays have largely eliminated such problems.

6.6.5.3 Multiple Echoes

These may occur when a strong echo is received from another ship at close range, usually abeam, and is caused by waves bouncing between observing and target ships. A second, third or more echoes may be observed on the radar display at double, triple or other multiples of the actual range of the radar contact.

6.6.5.4 Second Trace Echo

These are received from contacts at an actual range greater than the radar range setting. This type of echo appears on the radar at the correct bearing, but not at the actual range, and is caused by the arrival of the pulse after the following pulse has been transmitted. These can be recognised by a change in position after a change of pulse repetition rate, a hazy, streaky or distorted shape or erratic movements on plotting. They occur in conditions of abnormal refraction, particularly super-refraction.

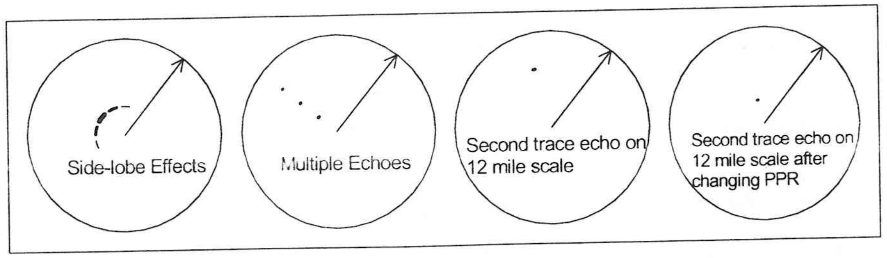

Figure 6.30 - Multiple Echoes

6.6.5.5 Interference and Spoking

Electronic interference occurs when another radar is operating in the area at the same frequency. Interference may appear as a large number of bright dots on the display, as curved dotted lines from the centre to the edge, or randomly scattered. They are distinguished easily as they do not appear in the same place during successive sweeps of the scanner. The effects are usually greater at longer radar range settings. Controls are available to suppress the interference.

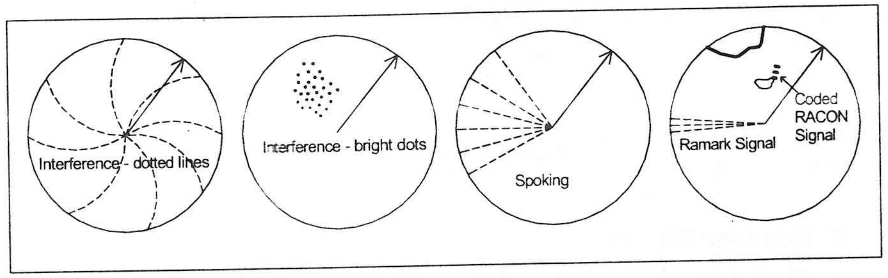

Figure 6.31 - Interference and Spoking

Spoking appears as a number of radial lines or spokes. Lines are straight and may appear all around or in a confined sector. If in a sector, it can be distinguished from a Ramark signal of similar appearance through its steady relative bearing. Spoking is a result of lack of maintenance or a need for adjustment.

6.6.5.6 Blind and Shadow Sectors

Parts of the ship's structure, such as funnels, masts, cranes, may reduce the intensity of the radar beam or block it completely. The blind sector will appear where the angle subtended at the antenna by the obstruction is more than a few degrees, whereas a shadow sector will appear where there is less reduction in the intensity of the radar beam beyond the obstruction. Within a shadow sector, while small targets at close range may not be detected, larger targets may be. Diagrams for blind and shadow sectors of each radar should be available on the bridge. The diagram can be prepared by swinging the ship in the vicinity of a small target, e.g., a buoy, at short range, and observing on radar.

6.6.5.7 Overhead Cables

The echo appears as a single echo at right angles to the cable and may sometimes be wrongly identified as a ship on a steady bearing. Any avoiding action results in the echo remaining on a steady bearing and moving to the same side of channel as the observing ship.

Authors Note:

Radar is a continuously developing technology. Most modern radars have additional features to assist navigation. Data, e.g. maps and parallel indexing plans, can be stored for retrieval at the time of use and for future referencing. However, it is the knowledge of its basic principles, set up and the skilful interpretation of display, that makes it the valuable aid to navigation that it is meant to be.

7 Extreme Weather And Navigation

There are some areas or circumstances that require special measures to be adopted for the safe navigation of the ship. It is to be expected that a mariner will not be warned about all hazards or dangers in good enough time. This chapter covers the aspects of navigation that are associated with such hazards.

7.1 Tropical Revolving Storms (TRS)

Unlike normal storms, a TRS has a deceptively small size and the weather experienced a few hundred miles from the centre may be beautiful. Because of this, the weather can deteriorate rapidly with the approach of the storm. Without the experience of encountering such a storm, it is difficult to imagine the violence of a fully developed TRS.

With the increasing use of satellites for meteorological observations, the warnings about the location of such storms have improved significantly. However, the mariner still needs to have a good understanding in order to properly read the signs of an approaching TRS and take avoiding action.

7.1.1 Description

7.1.1.1 Characteristics of a TRS

Tropical storms are intense depressions of around 500 miles in diameter that develop in tropical latitudes. Due to the steep pressure gradient, very high and violent winds are caused, generating phenomenal seas that are usually high and confused. Wind blows around the centre, in a spiral flow inwards - anticlockwise in Northern hemisphere and clockwise in Southern hemisphere. The TRS usually re-curves, as it reaches a maximum westerly longitude, and this makes it different from an ordinary storm. The centre of the storm is the eye, where the pressure is lowest. Typical wind forces associated with the storm are (depending on the pressure, the pressure gradient and the diameter of the storm):

- 200-250 nm — Force 6
- 100-200 miles — Gale Force
- 80 miles — Hurricane Force
- 5-50 miles — Close to Eye, much higher 100 kn to 175 kn

7.1.1.2 Categories Of Storms

- Tropical Depression — Winds of force 7 or less
- Tropical Storm — Winds of force 8 and 9
- Severe Tropical Storm — Winds of force 10 and 11
- TRS — Winds of force 12 and above

7.1.1.3 Areas of Formation

TRS predominantly form in six areas and are identified with different names:

- North Atlantic — Hurricane
- North Pacific (Eastern) — Hurricane
- North Pacific (Western) — Typhoon
- North Indian Ocean — Cyclonic Storm
- South Indian Ocean — Cyclone
- Southwest Pacific and Australian Areas — Cyclone

(In North and NW Australia a different version is called a willy-willy)

TRS only develop over oceans and usually originate near the seasonal location of the equatorial trough, usually between 5° – 15° N and 5° – 18° S. TRS are most frequent in a hemisphere during the late summer and early autumn. However, in reality, no month is entirely safe and storms can occur at any time.

7.1.1.4 Definitions

Track is the line that the storm centre has already moved over. Path is the direction in which the storm centre is moving. The storm may continue on the straight line path, or re-curve, or follow erratic movement and proceed in a loop. Vertex is the furthest westerly point reached by the storm centre. The storm has generally re-curved at the vertex. Pressure continues to drop forward of the Trough line and increases behind it. The centre of the storm is the Eye and includes the eye wall and its associated phenomenon. Vortex is used to identify the central calm of the storm.

Wind blows at an angle to the isobars, called the angle of in-draught, which varies with the distance from the storm centre, the pressure gradient and the rate of approach of the storm.

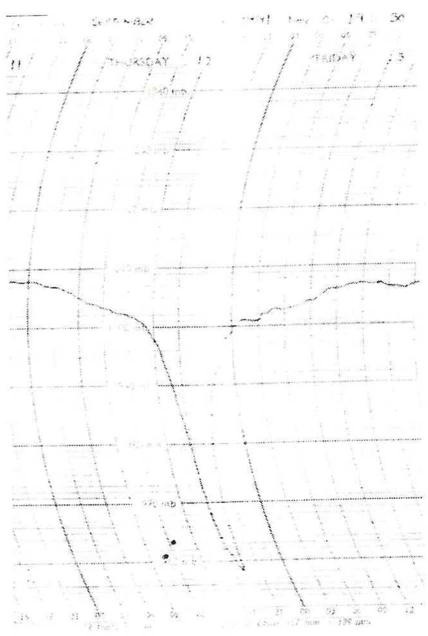

Figure 7.1 - Barograph Copy

Dangerous semicircle: This lies on the side of the path towards the usual direction of re-curvature, i.e. to the right hand semicircle in the N and the left hand in the S (away from the equator before re-curvature and towards the equator after re-curvature). It is called 'dangerous' because:

- If a ship is lying towards that side and forward of trough line, the storm will close in very rapidly with the normal movement of the storm
- Wind will tend to blow the ship toward the path and closer to the centre of the storm
- Re-curvature will decrease the distance from the centre.

Dangerous quadrant: The advance quadrant of the dangerous semi-circle is known as the dangerous quadrant, as it lies ahead of the centre. The three reasons listed for the dangerous semi-circle apply more strongly to this sector of the storm.

Navigable semicircle: This lies on the left hand side of the path in the N and the right hand side in the S (towards the equator before re-curvature and away from equator after re-curvature). A ship situated in this semi-circle will tend to be pushed behind the centre and the re-curvature of the storm will increase the distance from the centre.

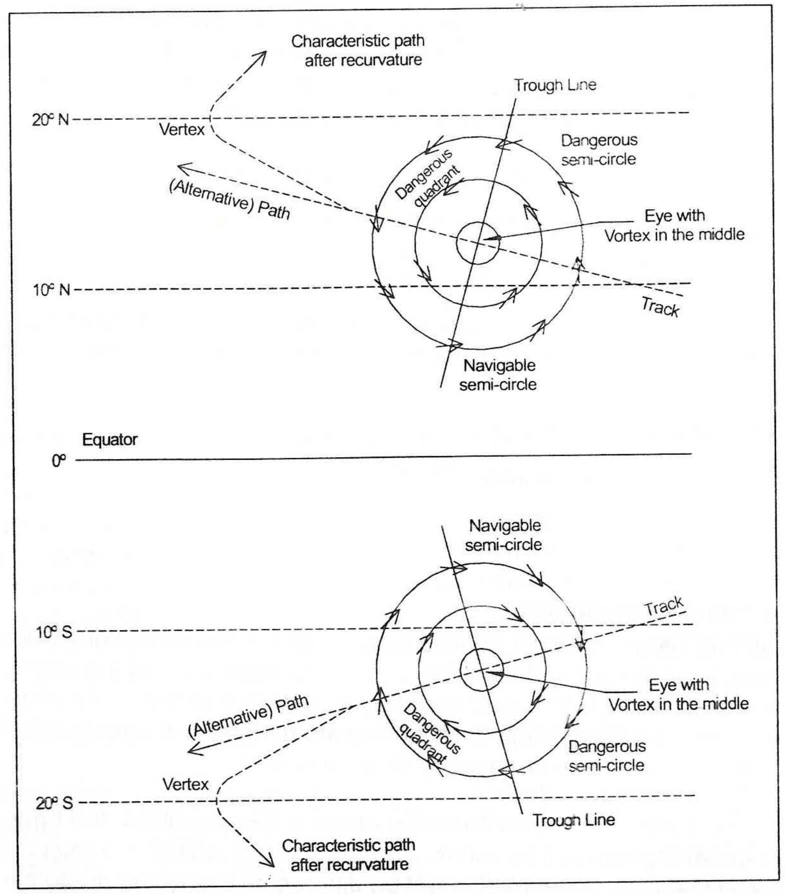

Figure 7.2 - Elements and Paths of a TRS

7.1.1.5 Movement

During the early stages the storm moves at about 10 knots and, as the latitude increases, it moves at about 15 knots. After re-curvature, the storm moves at 20 to 25 knots, attaining speeds of 40 knots in higher latitudes. Where the movement of storm is erratic, the speed of progress is seldom above 10 knots. In the northern hemisphere TRS move between 275° and 350° and when they re-curve at about 25° N and at 30° N they are moving NE. In the southern hemisphere they move between WSW and SSW, re-curve between 15° and 20° S and then follow an SE path. A general assumption is that a storm is not travelling towards the equator and, if in a lower than 20° latitude, its path is unlikely to have an easterly component.

7.1.2 Shipboard Detection And Location Of TRS

Early warning about the presence of a TRS is vital if the appropriate action to ensure safety of the vessel is to be taken. Detection and tracking is greatly assisted by weather satellites and the reports sent by authorities ashore. Details are broadcast at frequent and regular intervals from weather centres. However, it is still very difficult to pinpoint their centre at all times and to predict the path.

In order to decide an appropriate action, the mariner needs to have knowledge of:

- position or bearing of the storm centre
- path of the storm

On board the vessel, the mariner can detect the presence of a TRS and gain knowledge of its location and movement in a number of ways. These are categorised as:

- Visual observations
- Instrument observations
- Reports

7.1.2.1 Visual Observations

Swell: The first visible indicator in deep open waters is the exceptionally long swell approaching from the general direction of the origination point of the storm. The swell moves at a reasonably high speed and may be detected at distances of up to a thousand miles. The swell is apparent before the barometer begins to fall. The direction of swell may have changed in shallow waters.

Wind: The next sign is the wind. In areas where a TRS develops, the trade wind pattern is generally followed by winds. The presence of a TRS in a region changes the wind and the force and direction will be different to that of the predominant trade wind in the region.

'Buys Ballots' law can be used to determine the bearing of the storm centre. Wind generally blows in line with the isobars and has an angle of in-draught. The centre of the storm will be from 100° to 125° to the right of an observer facing the wind in the N (left if in S) when the storm is about 200 miles away. As a rule, the nearer an observer is to the centre the more nearly does the angle approach 90°, especially forward of the storm. The angle varies with the pressure gradient, the rate of progress of the storm and whether the observer is ahead or abaft of the storm. The wind direction during a squall should not be used for this purpose. In the S hemisphere, left is used instead of right.

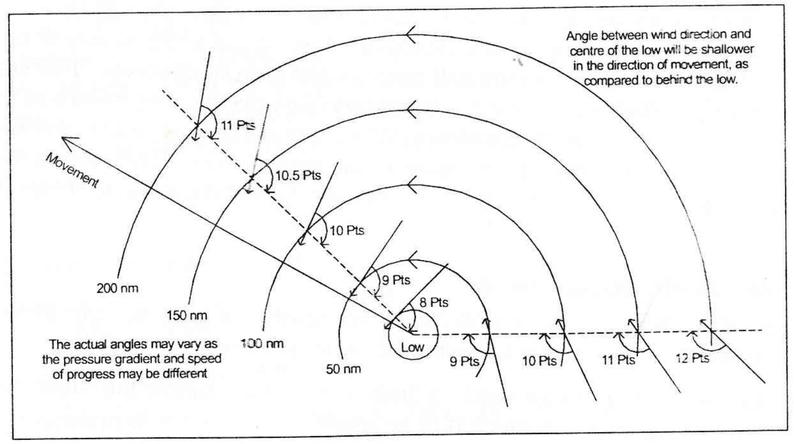

Figure 7.3 - Approximate Relationship of Wind Direction and Storm Centre in N Hemisphere

The distance from the storm centre may be estimated by reference to the force of the wind experienced at the point of observation. This information, coupled with two bearings taken 2-3 hours apart, should help to estimate the path of the storm. Allowance should be made for the movement of the ship between observations. The change in direction of the wind is an indicator of the location of the ship relative to the storm centre and movement.

Table 7.1 - Wind Shift and Ship Location Relative to TRS Centre

Wind Shift	Veering	Steady	Backing
Northern Hemisphere	Dangerous Semi-circle	Path of the storm	Navigable semi-circle
Southern Hemisphere	Navigable Semi-circle	Path of the storm	Dangerous semi-circle

If a ship in the northern hemisphere observes force 8 wind from ENE with a falling barometer, the centre of the storm would be between "S" and "S by W" at about 200 nm. As the pressure is falling, the vessel is forward of the trough line.

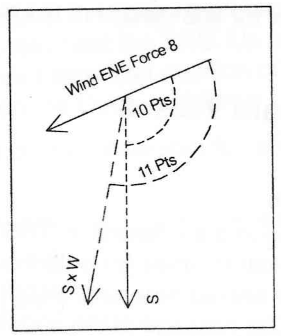

Figure 7.4 - Bearing of Storm Centre from Wind Direction

Clouds: The point of convergence of cirrus clouds, when they first appear, indicates the direction of the storm centre. If this point remains steady, the storm is approaching the observer's position. However, if this point shifts slowly in any direction, it indicates that the storm will pass to that side of observer. The storm is mainly formed of a dark mass of cumulonimbus (Cb) clouds. The centre of this mass of Cb indicates the direction of the storm. When the dense low clouds are overhead, their movement can provide an indication of the storm centre. The clouds move along the isobars and the centre is 90° to the direction of movement of clouds.

7.1.2.2 Instrument Observations

Pressure: All readings should be corrected for height, latitude, temperature, index error and diurnal variation. The following apply in all cases:

- Corrected barometer reading 3mb/hPa or more below the mean for the time of the year – suspicion is aroused.
- Corrected barometer reading 5mb/hPa or more below the mean for the time of the year – little doubt about the existence of storm in the vicinity.
- Cessation in diurnal variation - possibly a malfunctioning barometer.

A change of pressure also indicates the location of the vessel relative to the storm. If the pressure is falling, the vessel is forward of the trough line and if it is increasing, the vessel is abaft the trough line. Where there is no change, the vessel is on the trough line.

Radar: Radar capable of operating at long range, 98 nm or 120 nm, may display the exact position of eye of the storm. Since there is a lot of rain within these distances from the storm centre, the observation of individual echo returns, moving tangentially around the eye, can be spotted.

7.1.2.3 Reports and Warnings (see chapter 11)

The radio, NAVTEX, SafetyNET and facsimile messages provide reports about the location and movement of storms. The reports are based upon the most up to date information available to the meteorological service who have originated the report. Reports are also made by Masters of ships encountering a TRS. It is important to note that any change since the receipt of such information should not be considered a part of the reports available to the mariner. It is more important for the mariner to make onboard observations for knowledge of the location and movement of the storm.

7.1.3 Actions On Board Vessel

7.1.3.1 Prior To Detection

Vessels transiting or trading in areas prone to TRS activity, particularly during the TRS season, should establish routines for obtaining regular weather reports and facsimile charts. The OOW should note and record the weather every hour, particularly the pressure. The passage plans should allow for contingency actions

and alternate routes at various stages to the avoid storms, depending upon where they developed. Risk assessment should be carried out and recorded as part of planning. Before departure from any port within or transiting TRS prone areas, Masters should ensure that the vessel is well supplied as delays may be likely in the event of vessel encountering a TRS. Procedures from the company SMS, flag state and SOLAS must be followed. Weather reports should also be obtained while the vessel is in port.

7.1.3.2 Storm Detected / Reported

The first priority for any Master is the safety of their own vessel. Before taking any decisions, the Master should establish:

- Position or bearing of the storm
- Location of the vessel relative to the storm (semi-circle)
- Movement of the storm
- Sea room available and proximity to hazards

The security of the vessel should be ensured along with a good check on stability.

The Master should make an 'Obligatory' report. If a TRS is suspected nearby, SOLAS requires the Master to report the following, by all available means, to ships in the vicinity and to the nearest coast station:

- Position of the storm with the UTC and date
- Position, true course and speed of the ship
- True barometric pressure
- Pressure change in the previous 3 hours
- Direction and force of the wind
- State of the sea
- Height and direction of swell.

A report should be sent to owners, charterers and agents.

The bridge routine should be established during TRS encounters, as per the SMS procedures and contingency plans. An hourly log of weather should be maintained, along with any observation notes about the TRS. Up to date weather information should be obtained on a regular basis. The position of the storm and the projected movement should be plotted on the chart, as follows:

- A circle equal to the storm radius should be constructed, centred at the storm's position
- Tangents at 40° to the forecast path should be constructed either side of the storm
- 24 hours x speed of the storm provides the imminent danger area segment
- 48 hours x speed of the storm provides the probable danger area segment

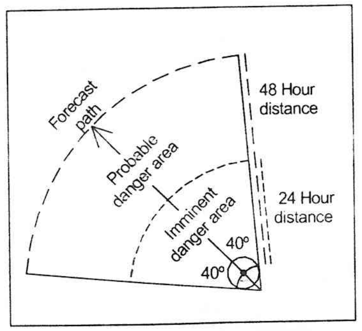

Figure 7.5 - Plotting TRS and Danger Areas

Where, through basic observations, it is not possible to ascertain the position of storm and the location of the vessel relative to it, the vessel should "heave to" either stopped or at steerage way, with wind on the bow.

Example 7.1

A TRS is moving at 305° T at 16 knots and is estimated to be 160°T at 200′ from a ship with a speed of 10 knots in the present conditions. Find:

- *The course to steer to pass at maximum distance from the storm centre*
- *The minimum distance the ship will pass storm on this course*

Solution and Comments

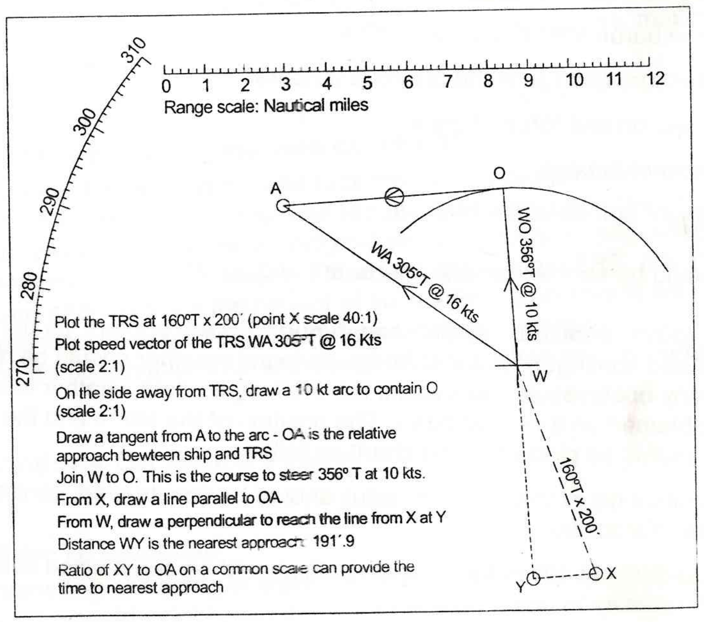

Figure 7.6 - Plot for Example 7.1

Considering the information available and its analysis, the course of action should be decided. There should be an attempt to remain outside a distance of 250′ from the storm centre. If this is not possible, every effort should be made to pass the storm at a distance of at least 80′. Where the ship is already at a safe distance from the storm, the course to steer can be determined by plotting.

7.1.4 Avoiding Actions

Every situation has to be resolved on an individual basis, taking into account the relevant facts. However, if recommendations are followed, the safety of vessel can always be ensured. The risk assessment should involve a review of the hazards, precautions to be taken and the advantages of any action when compared to its alternatives.

7.1.4.1 At Sea

Endeavour should be made to keep the ship in open waters with plenty of sea room in order to take avoiding action and, where practicable, the ship should never be taken into waters with restricted sea room.

If a storm is moving slowly, a vessel can easily outpace it if ahead of it and overtake if behind. Faster ships can overtake a TRS that is moving at normal speeds in tropical latitudes.

In likely areas, frequent barometer readings should be made and recorded. If it is certain that the vessel is behind the storm, or even in the navigable semi-circle, it will be enough to alter the course away from the centre, keeping in mind the tendency of a TRS to curve N and NE in the N hemisphere and S and SE in the S hemisphere.

In the Northern hemisphere:
The veering wind indicates that the ship is in the dangerous semi-circle. The ship should adjust course and proceed at all available speed, with wind 10° to 45° on the starboard bow depending on that speed. As the wind veers, the ship should alter course to starboard and get behind the storm.

Backing wind indicates that the ship is in the navigable semi-circle. The ship should bring wind on to the starboard quarter and proceed with all available speed, turning to port as the wind backs.

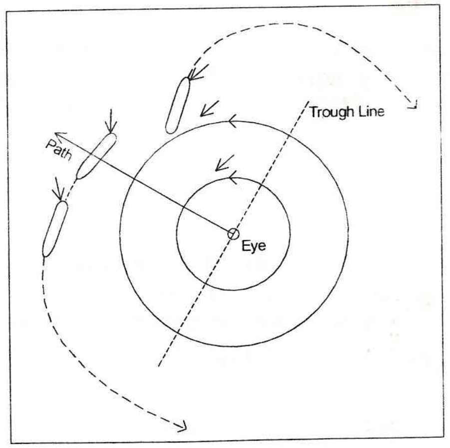

Figure 7.7 - Action to Avoid Storm in N Hemisphere

A steady or nearly steady wind direction indicates that the vessel is either in, or very nearly in, the path of the storm. She should bring the wind well on to the starboard quarter and proceed with all available speed. When well within the navigable semi-circle, keep the wind on the starboard quarter and proceed with all available speed, turning to port as the wind backs.

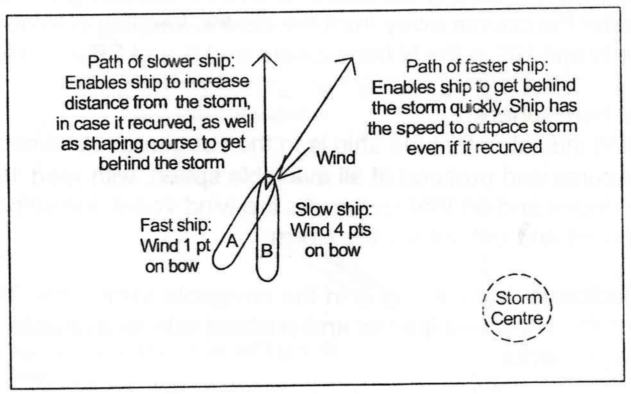

Figure 7.8 - Speed of Ship and Positioning of Wind on the Bow

Table 7.2 - Summary of Observations and Actions to Avoid a TRS

		Dangerous semi-circle	On path of the storm	Navigable semi-circle
North	Observation	Wind veering	Wind steady	Wind backing
North	Action	Wind 1-4 pts on stbd bow. Alter course to starboard as the wind veers	Keep wind well on stbd quarter and proceed towards the navigable semi-circle	Wind on stbd quarter. Alter course to port as the wind backs
South	Observation	Wind backing	Wind steady	Wind veering
South	Action	Wind 1-4 pts on port bow. Alter course to port as the wind backs	Keep wind well on port quarter and proceed towards the navigable semi-circle	Wind on port quarter. Alter course to starboard as the wind veers

7.1.4.2 Changes Observed

The combination of a number of variables helps to determine the position of the storm centre more frequently, which then makes it easy to decide on a safe course of action. Onboard observations must continue to detect any change and amend the actions taken earlier to ensure the continued safety of vessel and avoidance of unnecessary delay. Based upon the observations made by the bridge team on a vessel in the Northwest Pacific Ocean, the analysis and action is:

- Heavy swell from SSE
- Wind ENE, F 8 - 9, freshening and slowly veering
- Rapidly falling barometer

Swell: Near enough indication of bearing, the storm may have moved on a little.

Wind: The Vessel is in the dangerous quadrant and the storm centre is bearing between "S by W" and "S by E".

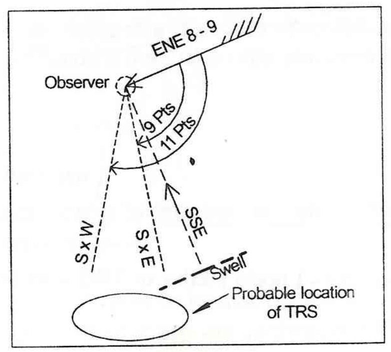

Figure 7.9 - Observations on TRS and Directions

Pressure: The Vessel is well forward of the trough line, as the pressure is falling rapidly.

The action at this stage is to adjust course to have the wind at 10° to 45° on the starboard bow, continue observations and alter the course to starboard as the wind veers.

If after a few hours the wind was observed to steady up and then start to back, it is evident that the storm has re-curved. The course should be adjusted to have wind on the starboard quarter to proceed in the navigable semi-circle, continue observations and alter course to port as the wind backs.

In the event of the wind continuing to veer, the wind must be kept on the starboard bow and the course altered to starboard as wind veers until the vessel is clear of the storm.

7.1.4.3 Proximity To Land

Quite frequently the vessel may be in close proximity to land and may even need to transit a strait or a channel when a storm happens to be in the area. Common examples are Taiwan Strait, Philippines, Mozambique Channel, Caribbean Sea and waters to North of Australia. For example, a vessel that is to the north of Taiwan and is intending to transit the Taiwan Strait may have to deviate from the passage plan in order to avoid a TRS that is heading for the coast of China.

The navigator needs to consider all of the options before deciding on the most appropriate course of action. The safety of the vessel and crew will take priority. The options should be plotted for reference and measurements.

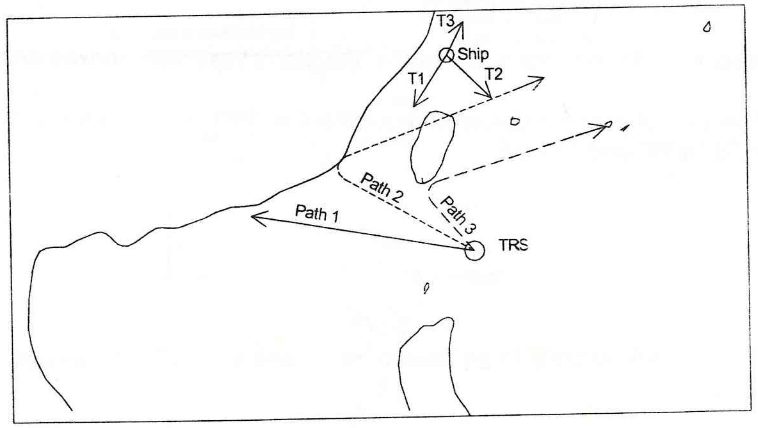

Figure 7.10 - Likely Paths of TRS and Ship Tracks

The paths of the TRS should be in line with the extreme historic tracks followed by TRS' in the region. It must be remembered that TRS movement may not follow the historic pattern and regular monitoring must be carried out. The Master must consider the following when making decisions about routes:

1. The position of the vessel relative to the storm (semi-circle)
2. Severity of weather along the option tracks
3. The minimum distance at which the vessel would pass the storm centre
4. The likelihood of the storm changing its direction and catching up with the vessel
5. Proximity to navigational hazards
6. Freedom of movement
7. Any change in steaming distance
8. Steaming time
9. The possibility of the vessel being caught up by the storm
10. The possibility of damage

Table 7.3 - Summary of Evaluation Criteria for Route Choice

	T1	T2	T3
1	Dangerous semi-circle	Dangerous semi-circle	Navigable semi-circle
2	Severe within Strait F 10->12	Severe in open sea F 8-12	Winds F 5-6
3	Perhaps very close	May be small or large	Large
4	Yes – even without re-curving	Yes – if it re-curved early	No
5	Within Strait	Close to islands	Open sea or coast
6	Little	Significant	Sufficient
7	None	Increase of about 400′	Increase over 600′
8	Increased as speed lost - TRS	Due to distance and TRS	Due to distance
9	Yes	Yes	No
10	Severe	High	None

As can be seen from the table, there are dangers involved with both T1 and T2. The choice should be T3, as it is hazard free and only involves increased distance and steaming time.

7.1.4.4 In Harbour or at Anchor

For a ship in port, the best choice is to proceed to sea at the earliest opportunity and when the storm is some distance away.

For a ship at anchor, the best choice is to heave up anchor and proceed to open waters. If there is not enough time or there are technical difficulties so that she is forced to stay at anchor, the following should be done:

- Both anchors should be used in an open moor
- As much cable as possible should be paid out
- Engines ran ahead (depending on wind force) to reduce strain on the cable.

For a vessel in port or at anchor the options available are:

- Stay in port (if in port already)
- Proceed to a storm anchorage
- Proceed to sea

The chosen action depends upon how far away from the port or anchorage the TRS is going to pass, the severity of hazards, the likelihood of precautions failing or the comparative advantages. The three general choices are considered separately:

Port

Advantages: If the vessel is well secured and there is no sea running, the decision to stay in port is a safe option, especially when the ship is well up river or where the storm is going to pass well clear.
In cases of extreme emergency, life can be saved by moving to shelters ashore.
Some assistance from the authorities is possible.

Precautions: Moorings should be doubled/trebled up.
Reports on the storm's movement should be received regularly.
Security of the vessel's gear, sufficient ballast and adequate stability should be ensured.
Stop cargo operations
The engine should be kept on immediate readiness.
Tugs should be ordered to standby.

Hazards: If a storm passes over the port, the ship is likely to surge alongside and land heavily on the berth, or other structures on the berth
Authorities may close the port and order all vessels to leave. The vessels may not be fully prepared and there may not be enough tugs or pilots to handle all vessels in time.
Damage may be caused by the bottom making contact with the seabed.
The vessel is immediately in peril if moorings break/fail.
Negative storm surge and up-swelling of water onshore may cause smaller vessels to end up 'out of channel' and on land.
As the storm approaches, tugs may not remain on station and it is probably too late to move to sea.

Storm Anchor

Advantages: The selected storm anchorage is likely to be well sheltered and with adequate depth.
The swell and sea in confined waters may not be very high.

Precautions: Routine observations, analysis of the situation and recording of findings.
Reports should be received regularly.
The Security of the vessel and its stability should be ensured.
If required, the decision to move out to sea must be taken at an early stage.
Both anchors should be laid out in open moor on a long scope.
The engine should be used ahead to ease strain on the anchor cables and prevent the anchor dragging or the cables breaking.

Hazards: Other vessels at the anchorage may make contact with own vessel and anchor cables may foul.
Other vessels may drag anchor and drift on to own vessel.
Reduced chance of receiving assistance at anchorage when a storm is overhead.
If a vessel is not sufficiently ballasted, or secured, or has inadequate stability, she may encounter serious problems.
Insufficient power or any defects may cause problems.
During the passage of a storm, if a vessel drags her anchors, it may be difficult to find a way out from the anchorage to the sea.
In shallow waters, damage may be experienced due to excessive rolling and pitching and the ship's bottom making contact with the seabed.

Sea

Advantages: The vessel is not dependent upon the availability of services such as tugs or a pilot for manoeuvring.
Freedom of movement allows the advantage of being able to clear away from an approaching storm.

Precautions: Routine observations, analysis of the situation and recording findings.
Reports should be received regularly and transmitted as needed.
Security and stability of the vessel should be ensured.
If a ship is at port or an anchorage, the decision to move out to sea must be taken at an early stage.
Freedom of movement must be maintained.

Hazards: It may not be possible to receive any assistance at sea and if the vessel is lost to sea, there is little chance of survival of the individuals onboard.
If the vessel is not sufficiently ballasted or secured, or has inadequate stability, she may encounter serious problems.
Where a vessel is caught on a lee shore, with restricted sea room, she may run aground, with serious consequences for safety of life.
Insufficient power or any defects may hamper manoeuvring.
There is a possibility of running out of fuel if sufficient reserves are not available.
In shallow waters, damage may be experienced due to excessive rolling and pitching and the ship's bottom making contact with the seabed.

7.2 Planning For and Information on Ice

Ice is of direct concern to navigators who are going to encounter it as it affects quite a few aspects of navigation:

- Appearance of features and landmarks
- Electronic aids to navigation
- Radar detection
- Celestial navigation
- DR
- Operation of compasses and logs
- Establishment and maintenance of aids to navigation
- Ship handling

This section does not cover the issues related to the formation of ice, but instead discusses the problems associated with its detection, navigation in its vicinity and working in regions where it is present

7.2.1 Sources Of Information

Knowledge of the presence, position and movement of ice is important when planning for resources and navigational procedures. The sources of information include:

- Mariner's Handbook
- Ocean Passages for the World
- ALRS
- Sailing Directions
- Ice charts
- Routeing charts
- Weather facsimile charts
- Ocean routeing services
- Weather and Ice reports
- NAVTEX and SafetyNET ice reports (see chapter 11)
- International Ice Patrol
- US Coastguard, US Navy Ocean Office, Canadian Ice Reconnaissance Aircraft Facsimile Service, Baltic Ice Service
- Port Authorities, Pilots and Pilotage Authorities
- Ocean weather ships
- Ships departing from the Area

- Previous experience and knowledge of the individuals on board
- Previous records onboard if the vessel had been to the area before

7.2.2 Readiness Of The Vessel

A vessel that is expected to operate or proceed in ice must be prepared for the hazards posed. The following list of requirements is not exhaustive but provides a general guide:

- Appropriate ice classification and notation
- The main engine and steering gear should be reliable and well maintained
- Operational navigation and communication equipment should be in good order
- Operational radars should be capable of peak performance
- The vessel must be adequately ballasted and trimmed to have the propeller fully immersed in water. Trim should not be excessive.
- The ballast and fresh water tanks should not be more than 90% full
- Good search lights
- International Code of Signals and communication procedures
- Fenders
- Towlines
- Defrosters on bridge windows
- Where available, tinted screens should be used on the Wheelhouse windows (due to bright sunlight)
- Accommodation heating
- Anti skid salt/grit
- Personnel provided with protective and cold weather gear
- Navigational publications for ice regions and latest reports
- Adequate reserves of stores and bunkers
- If the vessel has steam mooring winches, steam must be left warming through on deck
- If the vessel is a Liquefied Gas Carrier, drain deck spray lines
- On Chemical Tankers and Liquefied Gas Carriers, drain lines to decontamination showers
- On tankers fitted with Pressure Vacuum Breakers, ensure Glycol is added
- On tankers, activate the Deck Seal heating coils
- In the Lifeboats, check that the water tanks are not more than 90% full. The engineers should check the lifeboat diesel tanks
- Use canvases to protect ropes and wires on mooring drums

7.3 Navigation in Ice Areas

All ice is dangerous, particularly because where there is some in the area of operation of the vessel there is a possibility of more in the proximity. Ice may cause physical damage to the vessel's structure, and can pose operational problems. Quite a few of the problems directly affect the safe navigation of the vessel.

7.3.1 Master's Duties

When ice is reported on or near their track, SOLAS '74 requires the Master of every ship to proceed at a moderate speed at night or to alter course to pass well clear of the danger area. On meeting dangerous ice, the Master is obliged under SOLAS to send a report both to ships in the vicinity and to the nearest coast station.

7.3.1.1 Contents Of The Obligatory Report

- Type of ice
- Position of the ice
- UTC and date of observation

7.3.2 Effects of Ice and Snow Presence on Navigation

7.3.2.1 Electronic Aids To Navigation

The antennas may be completely covered with ice or snow and may not detect any signal or may malfunction because of a short-circuit. The movement of scanners may be obstructed or they could be completely covered under ice or snow. GPS and other electronic aids can be used for positions after applying the errors.

The echo sounder trace may be lost due to ice under the ship or because of the hull noises. The pressure (Pitot) tube or impeller type speed logs may have to be retrieved to prevent damage from any ice passing under the hull.

Impact with ice and frequent changes of course and speed introduce errors to the gyro compass. Such errors may be slow to settle.

7.3.2.2 Use Of Charts / Landmarks / Topography

The navigational chart provides the coastal features without any ice or snow. The appearance of landmarks that are covered with ice or snow changes significantly, though many inlets and points may bear a marked resemblance to the charted features. The pack-ice limit may be mistaken for coastline when observed either visually or by radar.

Headlands where icebergs have grounded will also be longer and more extended than the actual headland.

Substantial errors in position are likely when using snow covered headlands for radar ranges or bearings, visual bearings, clearing bearings or as clearing marks.

In such circumstances the position must be checked by other means.

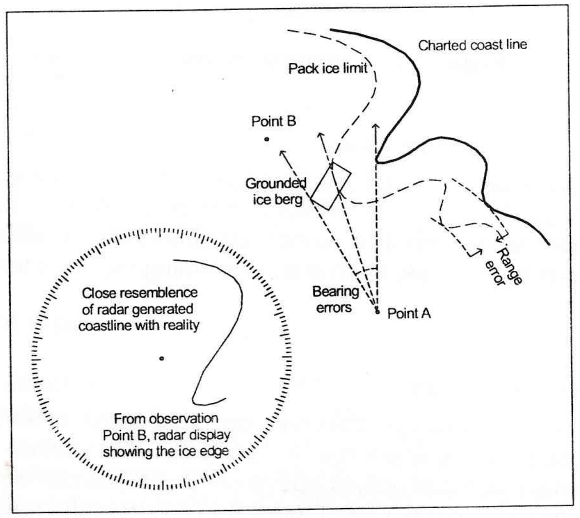

Figure 7.11 - Effect of Ice Presence on Bearings and Ranges

7.3.2.3 Lighthouses And Beacons

The detection or identification of lighthouses or beacons during daylight may become difficult, as snow or ice hides the identification features or, in extreme cases, the entire structure. During the night, the range of visibility of light may be impaired because of ice or snow on or around the lens.

7.3.2.4 Sectored Lights

Frost or ice on the lens of sectored lights is liable to significantly change their visibility sectors. The sectors may be unreliable but, if the lighthouse or beacon is correctly identified, it can still be used for taking bearings. These should be used with extreme caution and under such circumstances the mariner should confirm the position of the vessel using other means.

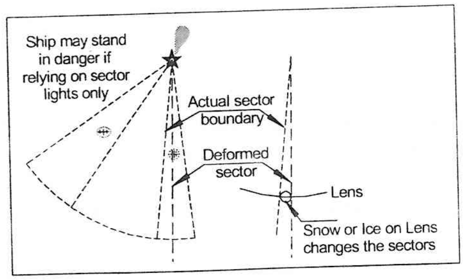

Figure 7.12 - Changes of Sector due to Ice

7.3.2.5 Floating Navigational Aids

Floating navigational aids are liable to be set adrift by the force of ice, or may simply drag their moorings. They may be hidden under ice or snow or may not be on station, as they are sometimes removed by authorities during the ice season. The mariner should be cautious in their use, even after confirming their position when ice is affecting the floating aids.

7.3.2.6 Celestial Navigation

False horizons frequently can be observed on ice because of refraction or mirage. Sights may not be possible where the horizon is covered with ice or snow. In such cases reverse angle sights of bodies above 60° in altitude can be considered in the vicinity of ice shelves (see 8.6.3 and Figure 8.11). Where the horizon is covered with ice, the height of ice over the horizon can be subtracted from the height of eye (maximum error being 4´). Accurate DR is the key to satisfactory positions when transferring position lines.

7.3.2.7 Radar Use

Radar must be operated at peak operational efficiency, although it will still have limitations. In cases where there is no echo on the display, it does not mean the non-existence of ice. Echo return depends upon the inclination of the reflecting surface, its size and distance. In calm sea, all sorts of ice should be detectable. Sea or rain clutter will suppress small ice fragments. Snow sleet and rain-storms will impair detection (also see 6.6.4).

Radar should be operated continuously, mainly on the 6 mile range, with frequent long range scanning for early detection of larger ice pieces afloat.

7.3.3 Signs Of Drift Ice

Drift ice is usually unexpected. Early warning of ice assists with preparedness. Visual detection can only occur within the geometric detection range, provided that the visibility is good and there is ample light. Radar detection also has limitations. However, there are signs that may indicate the presence of ice in the vicinity.

Ice blink appears as a glare, well before sighting ice. It appears as:

- whitish or yellowish haze during clear daylight
- whitish glare during day, with overcast sky or low clouds
- white patches in fog.

Gradual lessening of ordinary swell or abrupt smoothing of the sea indicates that the ice is to windward. Isolated fragments of ice are also noticeable downwind or downstream of ice. There may be a thick band of fog over the edge of drift ice.

The presence of marine life is another indicator of ice in the vicinity. In the Arctic, walruses, seals and birds could be spotted and around the Antarctic, Antarctic Petrel and Snow Petrel are noticeable.

A temperature of +1°C away from cold current indicates an ice edge 150 miles off, or 100 miles if wind blowing off the ice. At -0.5°C, ice is assumed to be no more than 50 miles off.

7.3.4 Signs of Open Water

In addition to the detection of ice, the mariner should also endeavour to find open water. Distinguishable dark streaks on the underside of the clouds indicate the direction of leads or open water and dark bands on the cloud at a high altitude indicates small patches of open water. Dark spots in fog may appear where open water is at a shorter distance. Additionally, the sound of surge in ice or a noticeable increase in swell indicates open water.

7.3.5 Icebergs

Complete reliance should not be placed on radar or any of the signs, as there are no infallible indications of the proximity of an iceberg. In general, if the ship is far from land, absence of sea in a fresh breeze indicates an iceberg to windward. Similarly, the presence of growlers or smaller pieces of brash ice also indicate that there is probably an iceberg is to windward. The sound of seas breaking far from land, or thunderous sound when icebergs calve, ice cracks or ice falls into sea are all useful indicators.

The iceberg may appear as a luminous white mass in fog when the sun is shining. During the night, the sighting of icebergs varies as follows:

- On a clear night, with no moon, icebergs are visible at 1 - 2 miles as black or white objects
- With moonlight they are easy to see, if the moon is behind the observer
- In cloudy sky, with intermittent moonlight they are difficult to see
- Cumulus or Cb clouds can create false impressions of icebergs at night

Changes in air or sea temperature, or echoes of a whistle or siren, cannot be relied upon for iceberg detection.

7.3.6 Ice Accretion

Severe ice accretion may occur on vessels that are experiencing sub-freezing air temperatures in association with strong winds. It is the precipitation and moisture in the air or sea water, in the form of spray, that freezes on the vessels structure. The conditions are difficult to forecast and since they exist within a large air mass, it is not always possible to avoid them within the time that warnings are received. Ships do not move very fast and are unlikely to clear the area of ice accretion by the time warnings are received.

7.3.6.1 Actions to Ensure Safety

The following actions are possible options available to the mariner in these conditions:

- Steer towards warmer conditions, or seek shelter
- Head into the wind at minimum speed to reduce spray
- If the weather does not allow the vessel to head into the wind, run before the wind at minimum speed to maintain steerage

If all fails and ice is building up on the vessel's structure, the last resort is to physically remove it as the adverse effects on stability due to the mass of ice may be enough to capsize the vessel.

7.3.6.2 Obligatory Report

On encountering air temperatures below freezing that are associated with gale force winds and causing severe ice accumulation on ships, the Master is obliged under SOLAS to send a report to ships in the vicinity and to the nearest coast station, covering:

- Air and sea temperatures
- Force and direction of wind
- Position of the ship
- UTC and date of observation

7.4 Operating in Ice

The basic rules are:

- Keep moving, even if very slowly
- Try to work with the ice movement and not against it
- Excessive speed leads to damage

7.4.1 Factors to be Considered Before Entering Ice

The vessel should not enter ice where an alternate route is available. Full regard should be made to the type of ice, the time of year, weather conditions and the area of operation. In addition, it is important that the ship has ice classification and, if required, icebreakers are available for assistance.

The hull, machinery, steering gear and critical equipment must be in a good state and the ship should have enough bunkers and stores. Manoeuvring characteristics of the ship, the draught in relation to the available depth of water, how well immersed the propeller tips and rudder are, along with the experience of the Master and officers are all important considerations. A proper passage plan based upon the most up to date reports on the ice, open water and leads should be prepared.

7.4.2 Ship Handling in Or Near Ice

7.4.2.1 Factors Dictating Entry

It is preferable to enter during daylight hours only. Entry or navigation at night, or in reduced visibility, should be avoided. If forced to proceed, good searchlights are essential.

Where practicable, entry should be planned from leeward as the ice is likely to be less compacted and there would be less wave action. Entry should be attempted at right angles, at reduced speed, at one of the bights.

7.4.2.2 Proceeding

The engine must be ready for immediate manoeuvre at all times. Once a vessel is in ice, the speed should be increased to maintain headway and control. The ship proceeding very slowly is likely to become beset, whereas a ship proceeding very fast risks damage. Use should be made of leads through the ice. The rudder should be amidships when going astern. If ice goes under the hull engine revolutions should be reduced immediately.

7.4.2.3 Anchoring

Anchoring should be avoided in heavy concentrations of ice. Anchors should be weighed if the wind is likely to move the ice on to the ship as the anchor and cable will be strained by the full force of moving ice. The anchor-party and windlass should be on immediate notice, with the engine on stop and ready to run if required.

7.4.2.4 A Ship Beset In Ice

The hull of a ship that is stuck in ice can get crushed. A ship beset in ice is at the mercy of ice movement. The engine should be kept turning slowly to keep the propeller clear. Icebreaker assistance should be requested immediately. An icebreaker will clear the ship by clearing ice from her sides and her intended course. Where icebreaker assistance is not available, attempts should be made to free up the ship by going full ahead, then full astern and using maximum rudder one way then another. As the ship begins to move ahead, the rudder should be put amidships.

The ship can be freed by changing trim and heel, by internal transfers of fuel, etc. Use of anchors can help to move the ship by:

- Laying anchors towards each beam on the ice and attempting to move the bow
- By placing an anchor on ice astern and using the engine astern, to move the ship astern

Remember: "MAINTAIN FREEDOM OF MOVEMENT"

7.5 Working With Ice Breakers

The Master of an icebreaker directs any escorting operation. Icebreakers may make use of aerial reconnaissance to find the position of leads and open water. Escorted vessels should:

- Establish the position of commencement for the escorting service
- Amend the ETA if necessary
- Maintain continuous radio watch
- Follow the route ordered
- Proceed at the speed ordered
- Always follow the path cleared by the icebreaker
- Have towing gear rigged at all times
- The OOW should know the signals for icebreaker assistance in ICS
- Acknowledge and execute icebreaker signals promptly
- If the icebreaker stops in an emergency, the escorted ship should stop immediately either by going astern on engine or ramming into the ice.

If the icebreaker is proceeding rapidly, the channel will be wider than its beam and fragments of ice will be left in the channel. This can slow down a following ship or may even cause a block. The Master of the icebreaker decides on the minimum and maximum distances from the icebreaker (minimum distance is the stopping distance and maximum is dependent upon ice conditions to keep the channel open). The distance may have to be reduced to a few metres if the channel is likely to close.

The icebreaker can decide to tow as well. The icebreaker can tow at short or long stay and usually connects the towline well forward on her deck. The icebreaker may ask for the engine of the towed vessel to be run at a particular speed.

7.5.1 Working in Convoys

The Master of the icebreaker will order the sequence and distance between the ships, which should be carefully maintained. If the speed is reduced, the ship astern must be informed immediately. The ship ahead and astern, as well as the ice, must be carefully watched. Light and sound signals must be repeated promptly by ships in the column, in turn and in sequence.

7.6 Navigation in High Latitudes

In addition to problems related to ice and snow, navigation in high latitudes requires particular care due to the convergence of the globe at the poles and the scarcity of navigational information. High latitude factors do not necessarily apply to ice navigation

7.6.1 Concept of Time

As time zones meet on the poles, local time has little significance. The normal phenomenon of day and night are not noticed as there may be very long days, nights and periods of twilight.

7.6.2 Charts and Bearings

Charts are based largely on aerial photography. Soundings, topography and navigational information are sparse in most polar-regions. The geographical positions of features may be unreliable and errors in their positions will become considerable as the distances increase.

Most regions are covered by gnomonic charts. Bearings (visual or radar) have to be treated as Great Circles, unless these are of nearby objects. Half-convergency should be applied where bearings have to be plotted on Mercator charts.

7.6.3 Meridians and Parallels

Meridians converge at the poles and the perimeter of parallels reduces considerably (cosine of $90° = 0$). Excessive longitudinal curvature renders meridians and parallels impracticable for use as navigational references. The only significance of this is for plotting positions derived from electronic systems, such as GPS.

7.6.4 Dead Reckoning (DR)

It is good navigational practice to keep careful observation of course, speed and time, in order to maintain a large-scale plot of the ship's track. As supporting data, such as information on tides and current, is not widely available it will be difficult to maintain an accurate reckoning of the ship's progress. Every opportunity to fix the ship's position should be taken. Systems like GPS, etc., have greatly reduced the need for DR, but it should still be maintained as continued signals from GPS satellites may not be guaranteed.

7.6.5 Use Of Compasses

At or near (85°) the geographical poles, the gyrocompass becomes useless as it loses all of its directive force. The Gyro is generally reliable up to a latitude of about 70°. At the magnetic poles, the magnetic compass becomes useless as it loses all of its directive force. Impact with ice and frequent changes of course and speed introduce errors that are slow to settle. Frequent comparisons of the gyro and magnetic compass should be made and logged and azimuths taken regularly.

7.6.6 Electronic and Radio Aids

GPS provides global coverage and, if a receiver is fitted, it can be relied upon after making allowance for errors. Other position fixing systems can be relied upon where available, again after making allowance for errors. Radar set up properly and at peak performance can be very useful for detection purposes.

7.6.7 Celestial Navigation

Accurate celestial observations cannot be relied upon because of the long days and nights and extensive periods of cloud cover. The following points are important (also see 8.6.1 and 8.6.3):

- The sun rises once in 6 months at a pole
- The sun sets once in 6 months at a pole
- The sun's maximum altitude will be 23° 27' at a pole
- The moon rises once a month at a pole
- The planets rise once each sidereal year at a pole
- Stars with a declination of more than 23° 27' in the opposite hemisphere will never rise at a pole
- All bodies will have an upper and lower meridian transit (Passage)
- The best fix is from the stars
- Star observations may not be possible with the sun just below the horizon, during daylight or when there is total darkness (prolonged nights)

- Observations at low altitudes may have to be made (10° may be the best altitude)
- During daylight, the sun could be the only body visible and clouds usually hide it for much of the navigational season

The results of sights are usually good but abnormal conditions should be looked into, e.g., sub or super refraction. Transferred position lines will give a fix with questionable accuracy because of DR inaccuracies.

Author's note

At times, even with knowledge of the existence of a hazard, progress has to be made as the hazard is not likely to disappear and this requires additional safeguards to be taken to ensure safety. Proper navigation practices are such safeguards that ensure safety of life, environment and property.

8 Celestial Navigation

The positions and motion of heavenly bodies are predictable. Since the positions of these bodies can be referenced to the earth, the heavenly bodies can be used for navigational purposes.

8.1 The Celestial Sphere

An imaginary sphere, with the earth at its centre and an infinite radius is called the celestial sphere. Its reference marks are linked to the earth or the terrestrial sphere. Projection of the plane of the equator to the celestial sphere forms the celestial equator. It is also referred to as the equinoctial.

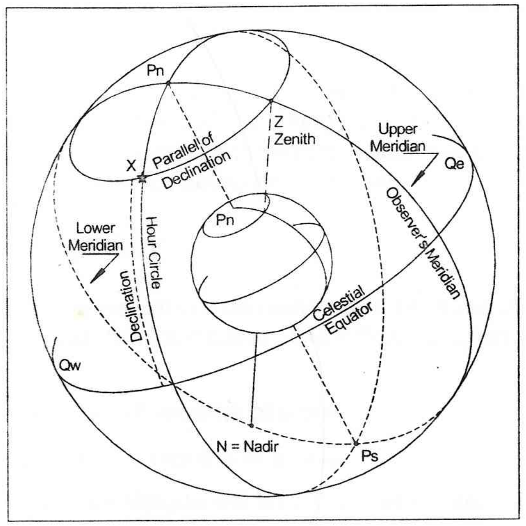

Figure 8.1 - Celestial Sphere and Components

The celestial meridian is formed by projection of the plane of the terrestrial meridian on to the celestial sphere. The celestial meridians are arcs of Great Circles passing through poles of the celestial sphere. If a line from the centre of the earth is drawn through the position of the observer, it reaches the celestial sphere at a point called the zenith, i.e., a point vertically overhead the observer. The point on the celestial sphere, on the opposite side to your zenith on the celestial sphere is called the nadir.

The part of celestial meridian that contains the zenith is called the upper celestial meridian (or upper branch) and the one containing the nadir is the lower celestial meridian (or lower branch).

A Great Circle that passes through a point, or any heavenly body on the celestial sphere, as well as through the celestial poles, is termed the hour circle. It moves with the body or the point as the celestial sphere rotates about the earth, whereas the celestial meridian remains fixed with respect to the earth. A circle parallel to the celestial equator and passing through the body is called the parallel of declination.

8.1.1 Celestial Co-Ordinates

As latitude and longitude indicate position on the terrestrial sphere; their celestial equivalents are the declination and the hour angle. The declination of a body is the arc of the hour circle or angle at the centre of the earth between the equinoctial or the celestial equator and the parallel of declination through the body. It is measured 0° to 90° north or south of the celestial equator. The angular distance between the parallel of the declination and the celestial pole is called the polar distance and is 90° plus or minus the declination, depending upon the pole being used. The declination of a few bodies changes significantly, e.g. sun, moon and planets. For this reason the hourly values of the declination of these bodies are noted in the nautical almanac. The declination of stars change very slowly, if at all, so it is noted only once every three days in the almanac for the selected stars.

Using North celestial pole:
(for example, declination 34 ° 20′N and 34° 20′ S)

Polar distance = 90° - 34° 20′ N = 55° 40′
Polar distance = 90° + 34° 20′ S = 124° 20′

The local hour angle (LHA) is the arc of the equinoctial (or the angle at the celestial pole) measured westwards between the observer's meridian and the hour circle through the body. Due to the rotation of the earth on its axis and the revolution around the sun, the hour angle of the bodies changes quite frequently. As there are numerous heavenly bodies, the hour angle data for each would require a huge publication. Two further references are used to minimise hour angle data. For the sun, moon, planets and the First Point of Aries, hourly data is noted with reference to the Greenwich meridian, whereas for stars the data is noted with reference to the First Point of Aries every three days. The Greenwich hour angle (GHA) of a body is the arc of the equinoctial (or the angle at the celestial pole) measured westward from the Greenwich meridian to the hour circle through the body. Sidereal hour angle (SHA) of a body is the arc of the equinoctial (or the angle at the celestial pole) measured westward from the hour circle through the First Point of Aries to the hour circle through the body.

For LHA:

Longitude East	GHA Least
Longitude West	GHA Best

GHA	=	145° 30′	145° 30′
Longitude	=	030° 15′ E	030° 15′ W
LHA	=	175° 45′	115° 15°

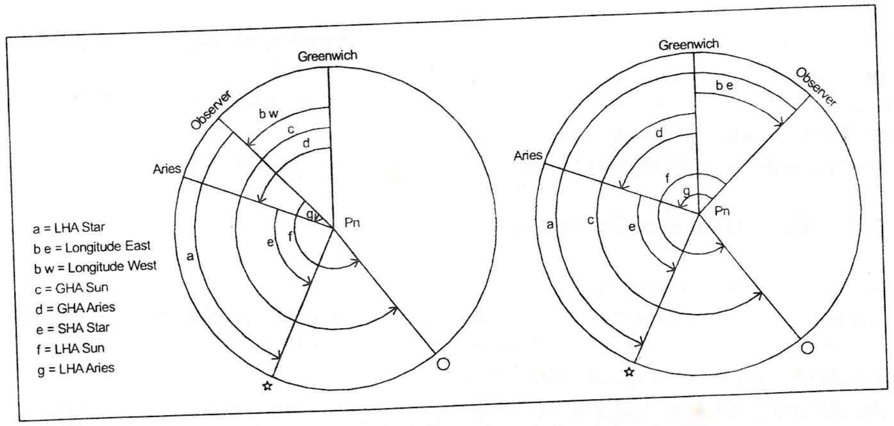

Figure 8.2 - Longitude, GHA, SHA and LHA

Example 8.1 (geographical position)

Find the geographical position of Venus on 4th May 2006, at 06h 28m 15s GMT.
Solution, using the Nautical Almanac

GMT (Date / Time)		(From Almanac) 4-5-06 / 06:28:15
Declination	00° 55´.1 S	0600
d Corrn	– 0´.5	Decreasing 1.0
Latitude	00° 54´.6 S	
GHA	310° 35´.0	0600
Increment	7° 03´.8	28m 15s
v Corrn / SHA	- 0´.1	-0.2
Sub total	317° 38´.7	
(360° -)		- 360°
Longitude	042° 21´.3 E	

8.2 Horizons and Altitudes

Since the celestial sphere is referred to the centre of the earth, the horizon can be used as a reference point for navigational purposes. There are a number of different horizons and all are perpendicular to the line between the zenith and nadir. The visible horizon is the line where the earth and sky appear to meet. It is also referred to as the apparent horizon. It varies with the height of the observer's eye above the sea and the refraction. The sensible horizon is an imaginary line through the observer's eye and the geoidal horizon is the line tangent to the earth at the observer's position. The Celestial (or rational) horizon is the line through the centre of the earth and is the reference horizon for the celestial calculations.

The celestial horizon in the reference system is the primary Great Circle. There may be other Great Circles called vertical circles, which are perpendicular to the celestial horizon and passing through the zenith and nadir. The arc of vertical circle through the body, between the celestial horizon and the zenith, is 90°. The arc between the celestial horizon and the body is the true altitude and the arc between the body and the zenith is the zenith distance. The zenith distance of a body is 90° minus the true altitude, where the body is above the celestial horizon. Where the body is below the celestial horizon, it can be 90° plus the true altitude.

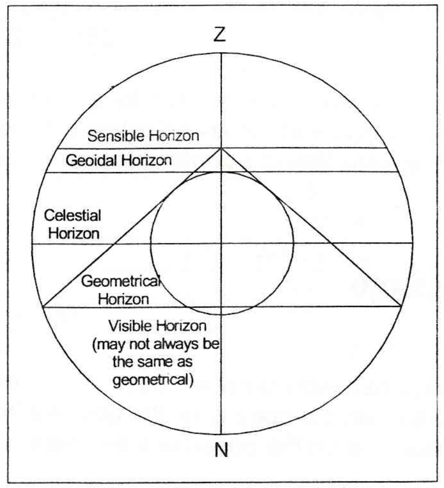

Figure 8.3 - Horizons

Example 8.2

If the sextant altitude of Jupiter was 35° 37´.4, find the true altitude if the index error is 1´.8 off the arc and height of eye was 14.2 m:
Using total correction table A2.
Using table A4 if pressure was 1020 mb and temperature was - 4°C.

Solution and Comments

From table A4 for 1020 mb and -4°C the zone letter is D. For D and an apparent altitude of 35°, the additional correction is -0´.1.

	Table A2	Table A4
Sextant altitude	35° 37′.4	35° 37′.4
Index error	+ 1′.8	+ 1′.8
Observed altitude	35° 39′.2	35° 39′.2
Dip	- 6′.6	- 6′.6
Apparent altitude	35° 32′.6	35° 32′.6
Total Correction	-1′.4	-1′.4
Sub total	35° 31′.2	35° 31′.2
Additional correction (Table A4)		- 0′.1
True altitude	35° 31′.2	35° 31′.1

The celestial horizon is above the visible horizon for any elevation above the surface. A body above the visible horizon and below the celestial horizon can be observed, i.e. a body with a negative altitude and a zenith distance greater than 90° .

8.3 Meridian Passage

Over the period of a day, a heavenly body will pass the observer's meridian. The meridian passage occurs when the body is on the observer's meridian. At meridian passage, P, Z and X are in line on the observer's meridian.

If the body is on the observer's upper meridian, it is called the upper transit or the upper meridian passage. At this moment, the LHA of the body is 0° and the bearing will be true north or south of the observer.

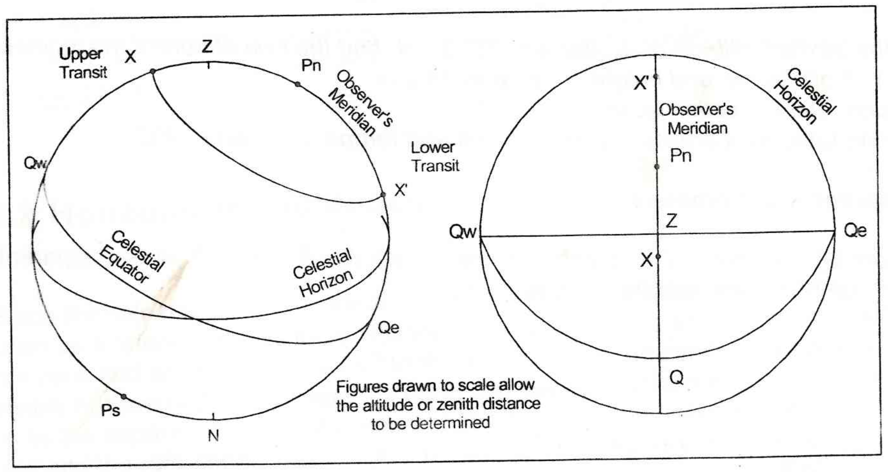

Figure 8.4 - Meridian Passage on Plane of Observers Meridian and Plane of Celestial Horizon

There are times that a body can be observed when it is on the observer's lower meridian. The only bodies that can be observed at lower transit are the circumpolar bodies. For a body to be circumpolar for the observer, the latitude and declination must be of the same names. The Lower meridian passage is also termed lower transit. At this moment, the LHA is 180° and the bearing is always 0° if the observer is in the northern hemisphere, and 180° if the observer is in the southern hemisphere

Example 8.3

Find the zone (+0500) time of meridian passage of Capella in 072° 42′ W on 4th May 2006.

Solution

LHA Capella	360° 00′.0	
SHA Capella	280° 43′.1	
LHA Aries	79°16′.9	
Longitude	W 072° 42′.0	
GHA Aries	151° 58′.9	
Nearest whole hours (GHA)	147° 31′.3	19 00 00
Difference (increment table)	4° 27′.6	17 47
LMT of merpass		19 17 47
Zone + 0500 (to be subtracted)		05 00 00
Zone time merpass Capella		**14 17 47**

In the case of problems involving a large East longitude, it is better to determine the approximate GMT first, in order to use the correct date.

Example 8.4

On 19th June 2006 in longitude 158° 30′ E, determine the precise zone (-1000) time of meridian passage of Venus.

Solution and Comments

Approx LMT merpass Venus	09 41 (June 19)
Longitude 158° 30′ E	10 34
Approx GMT merpass Venus	23 07 (June 18)

LHA Venus	000° 00′.0	
Longitude	E 158° 30′.0	
GHA Venus	201° 30′.0	
Nearest whole hours (GHA)	199° 57′.0	(18th) 23 00 00
v Corr	0.1	0′.5
Difference (increment table)	1° 33′.1	06 12
LMT of merpass		(18th) 23 06 12
Zone – 1000 (to be added)		10 00 00
Zone time merpass Venus		**(19th) 09 06 12**

At the meridian passage, if the sextant altitude of the body is observed and corrected, the true observed altitude can be used to determine the observer's latitude after applying the declination. There are only four variations possible:

- Latitude > Declination (both same names and upper meridian passage)
  Latitude = Declination –True Altitude + 90°

- Latitude < Declination (both same names and upper meridian passage)
  Latitude = Declination + True Altitude – 90°

- Latitude and Declination contrary names (upper meridian passage)
  Latitude = 90° – True altitude – Declination

- Regardless of the names and values of latitude and declination (lower meridian passage)
  Latitude = 90° + True Altitude - Declination

8.3.1 Time of Observation for Meridian Passage

A body is on the meridian when it is true North or South of the observer. In cases where a body is at a very high altitude, or close to zenith, the accurate bearing is not always possible.

A body would be observed by use of a sextant and, as it reaches maximum altitude, (or minimum altitude in case of lower transit) it is assumed that it is on the observer's meridian. The meridian passage of a body does not necessarily occur at the maximum altitude in the case of upper transit (or minimum altitude in case of lower transit). This may be the case when there is a large northerly or southerly component in the observer's movement. Change in the declination of the body may also introduce a small error.

It is preferable to observe for meridian passage at the calculated time.

Example 8.5

On 19th June 2006 in DR Posn 36° 28´.5N 039° 46´.5W, calculate the setting for the sextant to observe the sun's lower limb at meridian passage if index error of the sextant is 1´.5 on the arc and height of eye is 20m. State the bearing of the sun.

Solution and Comments

From the LMT of the meridian passage, the GMT would be worked out applying the longitude in time (LIT). Having obtained the true altitude, all altitude corrections are applied in reverse to obtain the sextant altitude, working upwards from the true altitude.

Almanac data		Altitude correction	
LMT merpass	12 01 00	Sextant Alt	76° 50´.9
LIT	+ 02 39 06	IE	- 1´.5
GMT merpass	14 40 06	Observed Alt	76° 49´.4
		Dip	- 7´.9
Declination	N 23° 25´.7	Apparent Alt	76° 41´.5
d Corrn	0.0	T Corrn	+ 15´.7
Declination	N 23° 25´.7	True Alt	76° 57´.2
Latitude	N 36° 28´.5	Bearing	180° T
TA = D – L + 90°			
True Altitude	**76° 57´.2**		

8.4 Azimuths and Amplitudes

8.4.1 Azimuth

An Azimuth is the horizontal direction of a point or body on the celestial sphere and is the arc of the celestial horizon, or an angle at the zenith, from the North or South point of the celestial horizon. It can be measured clockwise from 0° to 360° from the north point, or 0° to 90° clockwise or anticlockwise from the north or south points of the celestial horizon.

This is based upon time which, if known exactly, allows accurate calculation, provided that no errors have been introduced. It is preferable to select bodies between 30° and 60° in altitude.

Example 8.6

On 20th June 2006, at 07h 35m 25s GMT, in DR 63° 38´.5N 027° 26´.5W, the sun was observed to bear 077°G. Find the gyro error.

Solution and Comments

Date	20 June 2006	A = tan lat ÷ tan LHA	N 0.139646488
GMT	07 35 25	B = tan dec ÷ sin LHA	N 0.434555223
GHA Sun	284° 37´.7	C = A ± B	N 0.574184711
Increment	8° 51´.3	tan Az =1÷ (C x cos lat)	3°.922666329
Sub-total	293° 29´.0	Az	75°.7
Longitude	W 027° 26´.5	True Bearing	N 75°.7 E
LHA Sun	266° 02´.5		075°.7
Declination	N 23° 26´.1	Gyro Bearing	077°
d Corrn	0´.1	Gyro Error	1°.3 H
Declination	**N 23° 26´.2**		

8.4.2 Amplitude

Amplitude is the arc between the observed body on its celestial horizon and the point where the celestial horizon intersects the celestial equator.

The zenith distance at amplitude observation is 90°, therefore Napier's rules can be applied for the calculation of the amplitude angle. It is named North or South dependent up on the name of the declination and East or West, depending on whether the body is rising or setting.
The formula is:

$$\sin \text{Amplitude} = \sin \text{Declination} \div \cos \text{Latitude}$$

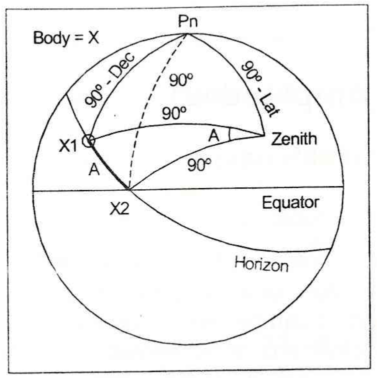

Figure 8.5 - Amplitude Reference

Example 8.7

On 20th June 2006, the observation of the rising sun gave a gyro bearing of 026°.5G in DR Posn 63° 30´.5N 027° 02´.5W. Find the gyro error.

Solution and Comments

Date	20 June 2006	sin Declination	0.39770844
Lat 63° 30´.5 N		cos Latitude	0.446067645
LMT for 19th	02 09	sin Amplitude	0.891587733
LMT for 22nd	02 09	Amplitude	63°.07
LMT Sunrise 62°	02 09		E 63°.1N
Increment	- 27	True Bearing	N 26°.9 E
LMT 63° 30´.5 N	01 42		026°.9
Long	01 48	Gyro Bearing	026°.5
GMT	03 30	Gyro Error	**0°.4 L**
Declination	23° 26´.1		
d Corrn	0.0		
Declination	23° 26´.1		

Amplitude observations are usually taken for the sun or moon rising or setting. In the case of the sun, the moment of observation is when the lower limb of the sun is half a diameter above the visible horizon. At this position the Sun is at the celestial horizon and the time is that of theoretical sunrise or sunset. The Zenith distance of a body is 90°. In the case of the moon, the moment of observation is when the upper limb of the moon is nearly on the visible horizon.

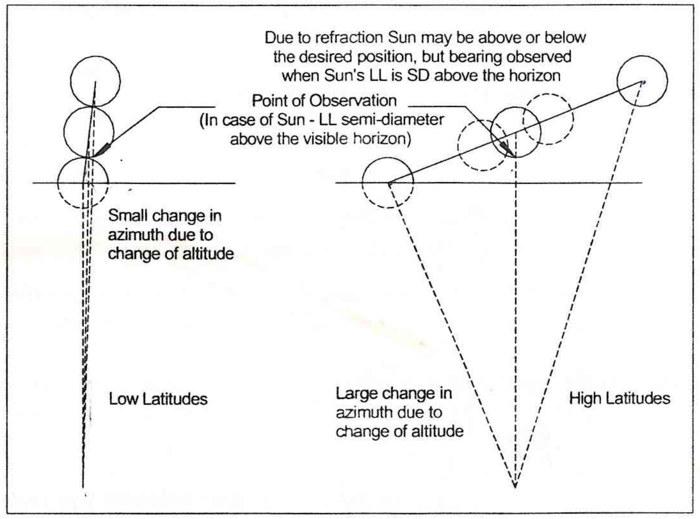

Figure 8.6 - Amplitude, High and Low Latitudes

If the refraction on the day or the position of observation was abnormal then, at the time of theoretical rising or setting, the body could be above or below the desired position. The problem is accentuated further in the higher latitudes, where the body sets or rises at a shallow angle to the horizon. Due to abnormal refraction, the body may be apparently lifted above the actual position or may be depressed below the actual position. The observer would not be able to spot the difference and would observe the bearing when, as an example, the sun was half the diameter above the visible horizon. This would cause an error in the observed bearing. Due to this, in higher latitudes the error obtained by amplitude method is less reliable when compared to the error obtained by the azimuth method.

If the Examples in 8.6 and 8.7 relate to the same ship with the gyro error obtained on the same day, at this high latitude the results of azimuth observation would be more reliable when compared to amplitude observation.

8.5 Astronomical Position Lines

8.5.1 Navigational Triangle

This is the spherical triangle formed by the arcs of the following Great Circles:

- Celestial meridian through the observer
- Hour Circle through the body
- Vertical Circle through the zenith and the body

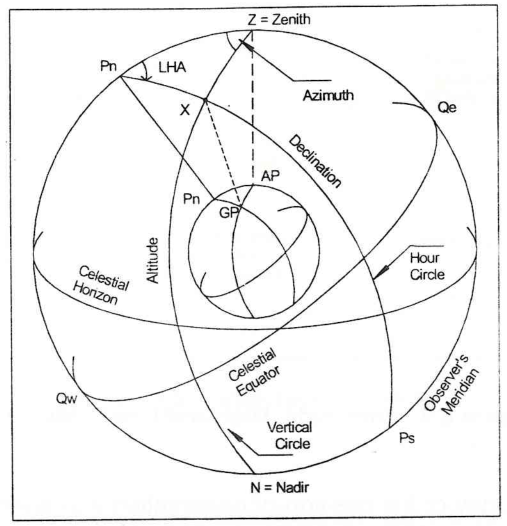

Figure 8.7 - Triangle on Plane of Observers Meridian

The three points of the triangle are P, Z and X for celestial pole, zenith and the body respectively. The terrestrial equivalents are the geographical pole, observer's assumed position and the geographical position of the body.

The navigational triangle can help solve a number of navigational problems.

- Where latitude, declination and hour angle are known, altitude and the azimuth can be determined
- The identification of a body can be made possible by working out declination and hour angle where latitude, altitude and the azimuth are known
- Where the hour angle, declination and altitude are known the azimuth can be calculated.

The astronomical position line is part of a Small Circle, which has the body "X" as its centre and passes through the zenith "Z". As the solution of the navigational triangle is based upon the observer's assumed position, the intercept distance is derived as the difference between the true and calculated altitudes (i.e. the zenith distance) and the position line runs perpendicular to the azimuth of the heavenly body.

The following assumptions are made when plotting the astronomical position lines:

- The true bearing of the geographical position of the heavenly body is the same at all points in the vicinity of the assumed position (DR or EP) and the observed position
- The position line is part of a small circle, which is plotted as a straight (rhumb) line and coincides with the arc of the observed position circle on the chart
- The direction of the intercept is part of a Great Circle forming the true bearing to or from the body and is plotted as a straight (rhumb) line
- When a number of position lines are to be plotted for a common time of position, these position lines are run onwards or backwards.

There are a few methods of determining the position lines. Examples for two are provided below.

8.5.1.1 Intercept Method (Marq St Hilaire)

In this method, the calculated zenith distance and the azimuth are worked out from the observer's DR (assumed position). The calculated zenith distance (CZD) is compared with true zenith distance (TZD) to determine the intercept. The position line is plotted perpendicular to the azimuth from the intercept terminal point. The intercept is plotted towards or away, depending on whether the TZD is less than or more than the CZD .

TZD less than CZD:	Intercept Towards (True Tiny Towards)
TZD more than CZD:	Intercept Away
True Altitude less than Calculated Altitude:	Intercept Away
True Altitude more than Calculated Altitude:	Intercept Towards

Cosine method can be used for the zenith distance:

cos ZX = cos PZ cos PX + sin PZ sin PX cos ZPX or

cos ZX = sin Lat sin Dec +/- cos Lat cos Dec cos LHA

8.5.1.2 Longitude By Chronometer

This method provides a calculated longitude through the DR latitude for plotting the position line. The plotting is simplified as no intercept is involved. The method is not suitable for a body approaching the meridian as a large displacement of longitude may be generated due to small errors. The calculation involves working out the LHA, which provides the calculated longitude:

LHA – GHA = East Longitude
GHA – LHA = West Longitude

$$\cos LHA = \frac{\sin \text{True Altitude} - (\sin Dec \sin Lat)}{\cos Dec \cos Lat}$$

Calculations involving long by chron have been added to the Example 8.8 solution.

Example 8.8

At 0825 on 06th May 2006, in DR Posn 34° 58′.0 N 146° 03′.0 E, the sextant altitude of the Sun's lower limb was 39° 42′.3 when the chronometer showed 10h 42m 06s. The chronometer has no error. Find the intercept and direction of position line if the index error is 2′.1 on the arc and the height of eye is 15.4m.

Solution and Comments

DR Latitude	N 34° 58′.0	Date and Z T	06 May'06 0825
DR Longitude	E 146° 03′.0	Zone - 10	10
		Greenwich date	05 May'06 2225
Body	Sun's LL		
C T	22 42 06		
C E	00		
GMT	22 42 06		
Almanac data			
Tabulated GHA	150° 50′.0		
Increment	10° 31′.5		
v Corrn SHA		Long by Chron Results	
GHA	161° 21′.5	GHA	161° 21′.5
Longitude	E 146° 03′.0	cos LHA	0.60824428
- 360° ?		Calculated LHA	052° 32′.2
LHA	307° 24′.5		307° 27′.8
Declination	N 16° 24′.8		
d Corrn + 0.7	0′.5		
Declination	N 16° 25′.3		
cos ZX	0.639540222		
CZD	50° 14′.5	Calc Longitude	E 146° 06′.3
Altitude			
Sext Alt	39° 42′.3		
IE	- 2′.1		
Obs Alt	39° 40′.2		
Dip	- 6′.9		
App Alt	39° 33′.3		
T Corrn	+ 14′.8		
True Alt	39° 48′.1		
TZD	50° 11′.9		

Intercept	2′.6 T		
Azimuth			
A	S 0.534847663		
B	N 0.371040178		
C	S 0.163807484		
tan Az	7.44946243		
True Az	S82°.4E		
	097°.6 T		
P/L	007°.6/197°.6		

8.6 Fix by Celestial Observations

To obtain a fix at least two position lines are required. Using celestial bodies, these position lines can be based upon observation of the Sun, Moon, Stars or Planets. During daylight, when the Sun is above the horizon, it is rare to see a celestial body other than the Moon by the naked eye., and this only when it is above the horizon. However, when Venus is not fixed by the Sun, its altitude and bearing can be pre-computed and observed during the day. If the Moon is not visible, and the Sun is the only body visible, a running fix will have to be used to fix the ship's position.

The following combinations are possible:

Sun – run – Sun
Sun – run – Meridian Altitude of Sun
Meridian Altitude of Sun – run – Sun
Sun – run – Moon or Moon – run – Sun
Sun – run – Star/Planet
Star/Planet – run – Sun (stars/planets during twilight only)

At night the horizon is not distinct enough to obtain the altitudes required for working out sights, the only exception being within three days of the Full Moon. As during the day stars and planets are not visible by the naked eye, and at night the horizon is not visible, sights of stars and planets can only be taken when both are distinct, i.e. during twilight.

The twilights are categorised as (when sun is):

Civil : Sunset to 6° below the horizon
Nautical : Sun 6° to 12° below the horizon
Astronomical : Sun 12° to 18° below the horizon

Total darkness occurs when the sun is 18° or more below the horizon. The best time for observation is at the beginning of nautical twilight in the evening and the end of nautical twilight in the morning. Since a number of bodies may have to be observed, a time window should be allowed when sun is between 3° and 9° below the horizon, i.e. half way between the period of civil twilight to, or from, half way between periods of nautical twilight. Just like the circumpolar concept, in certain latitudes twilight may also last all night, allowing sights to be observed more frequently.

8.6.1 Planning Sights

8.6.1.1 Selection of Heavenly Bodies

For a fix to be reliable, the selection of stars and planets needs some consideration. The following points should be considered when planning a morning or an evening sight:

- Using a star chart or globe, the stars and planets to be used should be determined
- 3 or more stars and/or planets should be selected. In case of partly cloudy sky, select an additional 4 standby stars
- The stars/planets selected should give the best cuts for position lines. At least two should be about 90° apart in the azimuth. In general, the bodies should never be less than 30° apart in the azimuth.

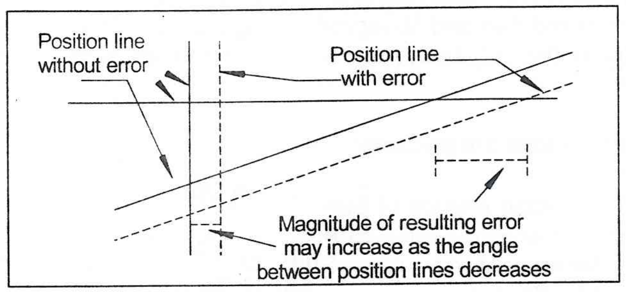

Figure 8.8 - Errors due to Small Angles Between Position Lines

- The best combination is 4 stars 90° apart within an azimuth. These combinations will have stars on opposite horizons, or all round the horizon. Opposite horizons will eliminate any abnormal refraction error
- Choosing stars with an altitude of between 20° and 70°, though 30° to 60° would be a better choice. Preferably, all stars should be on the same altitude, especially those on opposite horizons to each other. The refraction is in layers and, if the stars happen to be within similar layers to each other, abnormal refraction can be cancelled out.

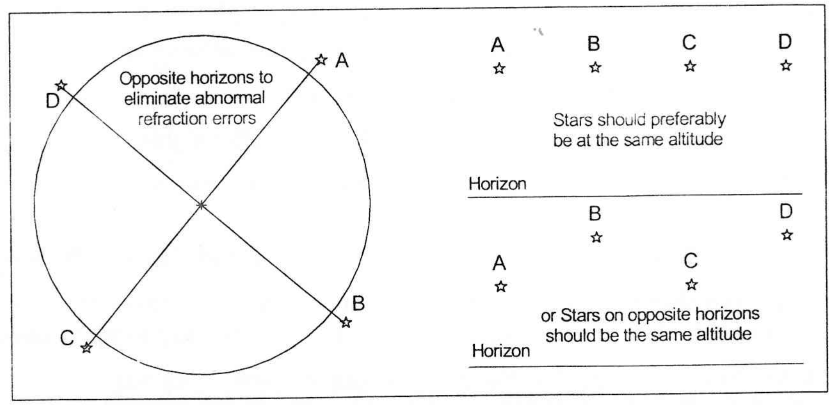

Figure 8.9 - Azimuth and Altitude of Stars/Planets

Planning should assist in the identification of stars or planets and should also help reduce the time loss between observations. The following should be considered:

- Make a general sketch of the approximate altitudes and bearings of the chosen stars relative to the ship's head, for identification. A sextant can be set to these altitudes to scan the horizon in the direction of the star for detection
- Make a note of the weather and the direction in which the horizon is likely to be clearest
- Care needs to be exercised while taking observations in order to make use of the clearest horizon
- Start taking sights from the eastern horizon first and then the West. In the morning the Eastern stars will fade away first and, in the evening, the eastern horizon will become indistinct first
- Observe stars as early as possible at evening twilight and as late as possible at morning twilight to make use of clearest horizon
- In the morning, start with the faintest star as it will not remain visible for long
- In the evening, start with the brightest star, as you will see it first and the best horizon will be available.

General precautions for sights taken at any time of the day are as follows:

- In clear weather take observations from the highest convenient position to take advantage of the clear distant horizon. This avoids errors caused by high waves obscuring the horizon and parallax

- Always swing the sextant a few degrees to each side of the vertical plane as the body is brought to the horizon. Adjustments to the altitude should then be made by micrometer, until it just touches the horizon
- When possible, check the sextant for side error before taking sights
- When possible, take the index error before and after sights
- When observing the Sun, use sufficiently strong shades to avoid any possibility of dazzle
- If the identity of a body is uncertain after taking altitude, take its bearing
- When the ship is rolling heavily, observations should be taken from close to the centre line of the vessel to minimise errors due to changing DIP
- In the tropics, it is best to place the sextant outside, in its box, 15 minutes before to allow it to warm up. This will stop the condensation forming as it would when taken from an air conditioned bridge to a warm/humid bridge wing

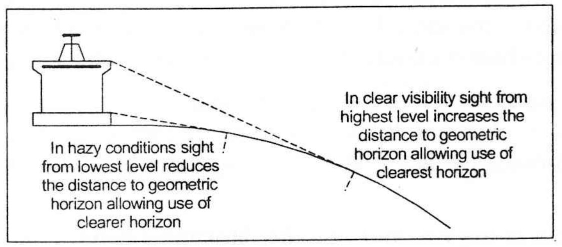

Figure 8.10 - Observation Points on Ship in Different Conditions

8.6.2 Sights in Hazy Conditions

- In haze or mist, take observations from the lowest convenient position as this will reduce the distance to the horizon where it is likely to be clearer
- With an indistinct, cloudy or hazy sun, align the middle of the disk with the horizon instead of UL or LL. (Altitude corrections, less than for SD, must be applied separately)
- When possible, take observations of a heavenly body in sets of three or five at approximately equal time intervals
- When the horizon is poor, it is essential to take several altitudes of each body and to set the sextant to a given increase or decrease between each observation. If time intervals are not equal, sights should be either discarded or used with extreme caution.

8.6.3 Abnormal Refraction

Opposite horizons:

A pair of stars on opposite sides of the horizon (almost 180° apart in azimuth) should be observed in order to cancel out the effect of refraction. When the two position lines are plotted, the linear or angular distance between them should be halved. A second pair 90° different in azimuth from the first pair should be observed and plotted in the same manner as the first pair (Example 8.11 illustrates this point).

Reverse angle sight:

A body at an altitude higher than 60° should be observed twice, once with the normal observation of least altitude and once with the reverse observation (180° - least altitude) on the opposite horizon. (NB: Sextant can only measure angles up to 120°. 180° - >60° = <120°). The two altitudes (corrected for index error) should be added and their sum subtracted from 180°. The resulting difference is the sum of dip and refraction in both directions, and is twice the value of dip and refraction where the abnormal refraction is believed to be the same in both directions.

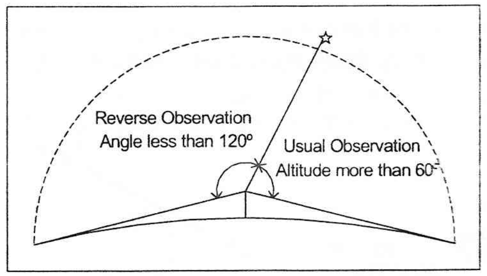

Figure 8.11 - Reverse Angle Sight

Application of corrections:

Nautical almanac table A4 for a range of temperature and pressure conditions temperatures and at different apparent altitudes.
Norie's tables provide separate correction tables for pressure and temperature against apparent altitude.

8.6.4 Plotting Sights

All of the position lines required for plotting a fix using stars and planets cannot be taken together. There will be a small time lapse between one observation and the next. The time between the first and the last observation could be significant. Therefore, it is important to run the position lines obtained by the stars and planets around a common time for which the position is required. The following examples demonstrate this effectively. In addition, the examples cover the various planning and analysis aspects of the stellar/planetary fixes.

Example 8.9

A ship steering 247°T at 16 knots obtained the following intercepts using the 0615 DR Posn 21° 12´ N, 154° 35´ E for all sights:

	Time	Bearing	True Altitude	Intercept
Star A	*0610*	*269°T*	*56°55´*	*1´.2 Towards*
Star B	*0617*	*330°T*	*31°42´*	*2´.3 Towards*
Star C	*0625*	*153°T*	*34°11´*	*2´.3 Away*
Star D	*0635*	*095°T*	*59°50´*	*7´.4 Away*

Plot these observations to find the vessel's position for 0615 hrs.

Solution and Comments

In general, the position should be run from the ITP, as has been shown in the plot below. Before plotting, it is important to decide the run-on or run-back for each position line. As the position is required for 0615:

Star A 0610 to 0615	5 minutes	run on	1´.33
Star B 0617 to 0615	2 minutes	run back	0´.53
Star C 0625 to 0615	10 minutes	run back	2´.67
Star D 0635 to 0615	20 minutes	run back	5´.33

Remember that the runs are for the common time of position and not necessarily from the DR. Principally, position lines should be run from ITP

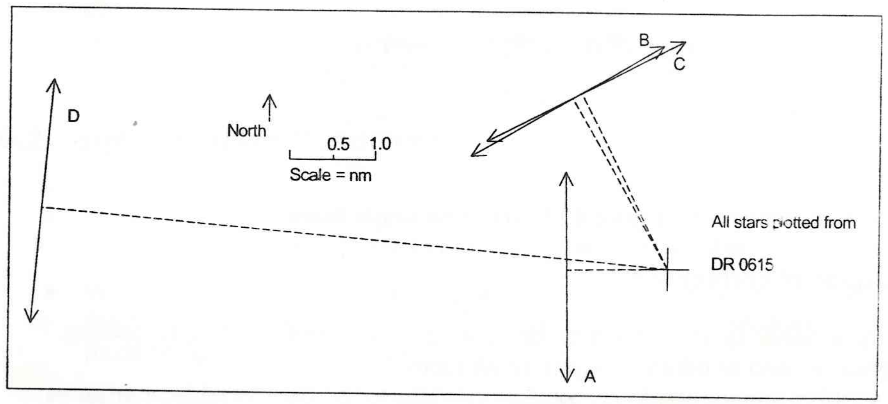

Figure 8.12 - Plot for Example 8.9

As can be seen, A, B and C would appear to cut in close proximity but star D is far away. In the next sketch, appropriate runs on track 247°T have been applied to position lines to relate them to a common time – 0615. It can be seen that this involves a lot of plotting and that there is a lot of information.

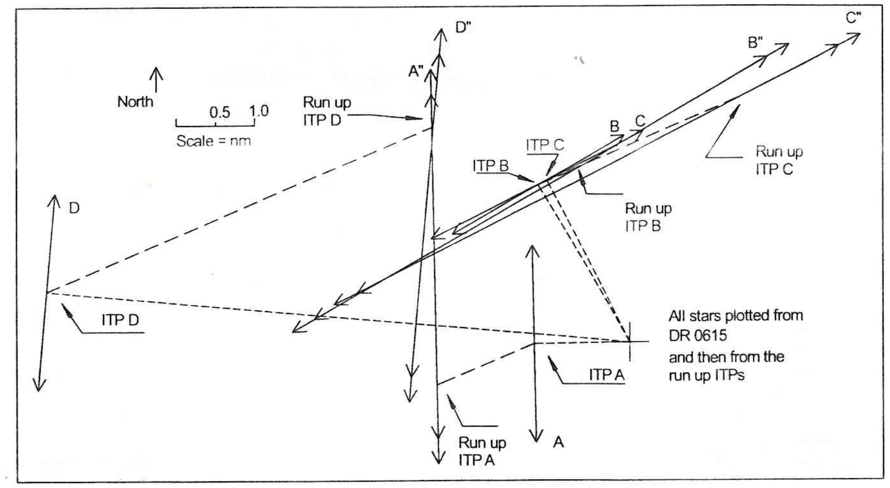

Figure 8.13 - Second Plot for Example 8.9

The plot can be simplified by 'running on' or 'back along' the track from the common time for the position (DR in this case). It will be noticed that the position lines plotted in this manner fall in exactly the same place as the transferred position lines after ITP 'run up'.

The Figures 8.12, 8.13 and 8.14 have been used for explanation and need not form part of any solution. The simplified plot for this example is provided at Figure 8.15 and is an appropriate solution for the example, complete with the observed position.

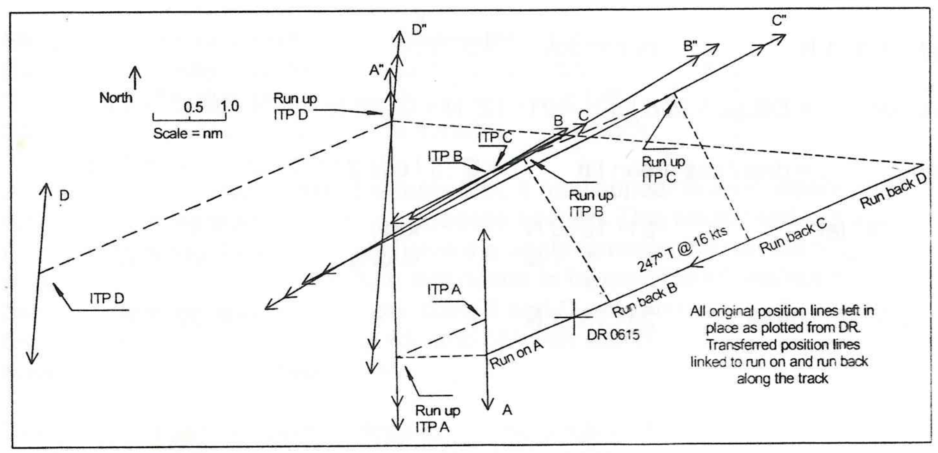

Figure 8.14 - Third Plot for Example 8.9

By observation, it can be seen that pairs of stars A and D, and B and C are on opposite horizons. The angles between their position lines have been halved. The fix is selected as the point at the intersection of the bisector lines.

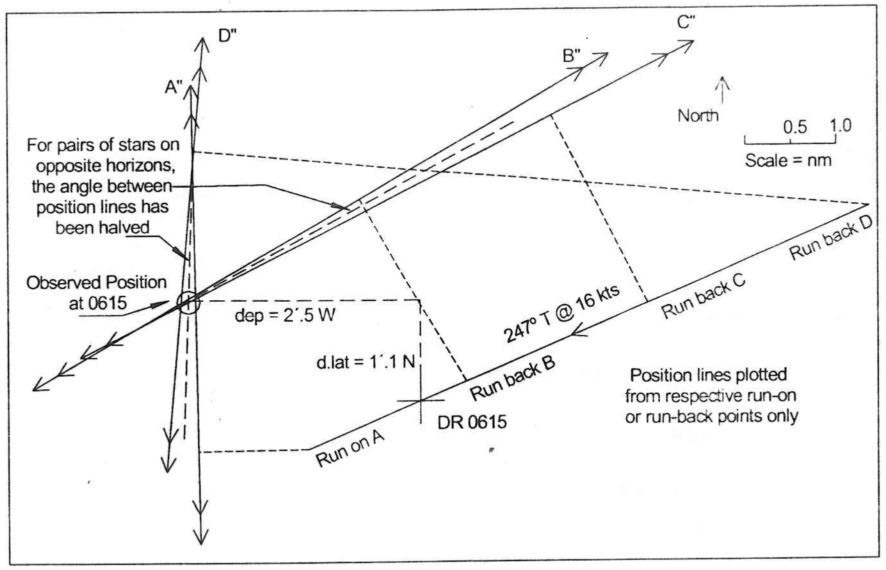

Figure 8.15 - Fourth Plot for Example 8.9

From the plot:

d.lat	= 1´.1 N	departure	= 2´.5 W
mean lat	= DR lat + ½ d.lat	= 21° 12´ N + 0´.55 N	= 21° 12´.55 N
d.long	= dep / cos mean lat	= 2´.5 / cos 21° 12´.55	= 2´.7 W

DR lat		21° 12´.0 N	long	154° 35´.0 E
d.lat		1´.1 N	d.long	2´.7 W
Position	**0615**	**21° 13´.1 N**		**154° 32´.3 E**

Reliability of Position

If it is necessary to comment on the reliability of an observed position, the following should be argued:

- Number of stars
- Azimuth between stars, 90°, but not less than 30°
- Opposite horizons
- Altitude between 20° and 70°
- Altitude of stars same or at least same for opposite horizon stars
- Resulting angle of cut between the bisector lines

Example 8.10

A ship steering 125°T at 20 knots observes the following stars:

	Time	*Bearing*	*True Altitude*	*Intercept*
Star A	*0539*	*284°T*	*52°45´*	*2´.1 Towards*
Star B	*0548*	*264°T*	*31°42´*	*1´.3 Towards*
Star C	*0600*	*045°T*	*44°16´*	*3´.9 Away*
Star D	*0609*	*169°T*	*34°28´*	*9´.9 Towards*

The 0545 DR position 38° 32´ S, 124° 25´ W was used for all intercepts. Find the vessel's position at 0600 hrs.

Solution and Comments

As the position is required for 0600:

Star A	0539 to 0600	21 minutes	run on	7´.0
Star B	0548 to 0600	12 minutes	run on	4´.0
Star C	0600 to 0600	0	on DR	0´.0
Star D	0609 to 0600	9 minutes	run back	3´.0

At first glance (having worked Example 8.9), it may appear to an inexperienced navigator that stars A and B are on opposite horizon. This would lead to a serious error as the navigator may simply halve the angle between the two stars. For opposite horizons, it is the azimuth that needs to be considered and not the angle between position lines. In this case, stars B and D are almost at right angle and the stars A and C have angles of 65° and 56° with star D. Similarly, stars A and C have an angle of 59° between them.

The position has been plotted close to the intersection of B and D, with allowance made for A and C. The actual intersection between the position lines of A, B and C is not the observed position. Remember that a position line should not be discarded as it is away from an intersection. In this case position line D has the best angles of cut with all other position lines.

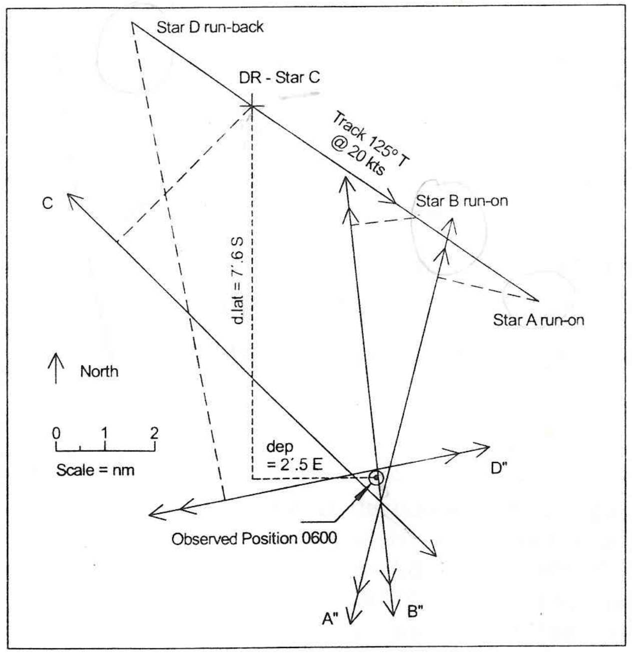

Figure 8.16 - Plot for Example 8.10

From the plot:

From the plot:
d.lat = 7′.6 S departure 2′.5 E
mean lat = DR lat + ½ d.lat = 38° 32′ S + 3′.8 S = 38° 35′.8 S
d.long = dep / cos mean lat = 2′.5 / cos 38° 35′.8 = 3′.2 E

	DR lat	38° 32′.0 S	long	124° 25′.0 W
	d.lat	7′.6 S	d.long	3′.2 E
Position 0600		**38° 39′.6 S**		**124° 21′.8 W**

Example 8.11

A vessel in DR Posn 43° 52′ N 135° 32′ W, steaming on a course of 255°T at 15 knots observes the Sun bearing 121°T at 0935 (+0900) on 05th May 2006. An intercept of 4′ towards was obtained. Index error is 1′.5 off the arc and height of eye is 16.5 m. Calculate:

- *GMT of the meridian passage of the Sun*
- *The setting on the sextant to observe the Sun's lower limb at the meridian passage*
- *The position of the ship at the meridian passage of the Sun when the sextant altitude is 62° 36′.*

Solution and Comments

As the ship is proceeding, the longitude for the meridian passage needs to be determined first. It can be determined by either the approximation or the iteration method. The calculation is on the following table. Using the results, the plot is:

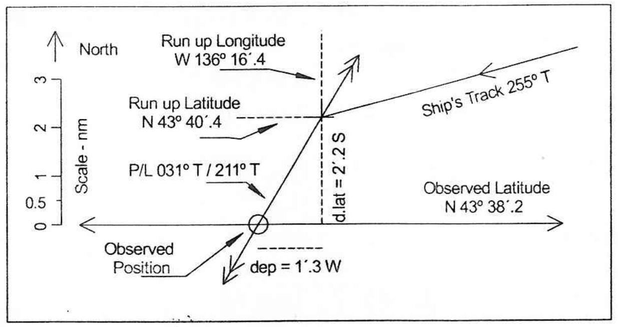

Figure 8.17 - Plot for Example 8.11

The accuracy of the above position is heavily dependent upon the course maintained by the vessel and the distance covered, apart from general errors (discussed later in this chapter). If all the errors were taken care of the fix would be reliable, as observed latitude at the meridian passage is very reliable and the position lines cut at an angle of 59°.

DR Latitude	N 43° 52′.0	Date and Z T	05 May'06 0935
DR Longitude	W 135° 32′.0	Zone +9	0900
Course / Speed	255°T / 15 kts	Greenwich date	05 May'06 1835
For ITP			
d.lat	4 x cos 59°	= 2′.1 S	
dep	4 x sin 59°	= 3′.4 E	
mean lat	lat ~ ½ dl.lat	= 43° 50′.95	
d.long	dep / cos m lat	= 4′.7 E	
ITP	N 43° 49′.9	W 135º 27′.3	
1st Approx		***1st run up posn***	Course = S75°W
LMT merpass	11 57	d.lat	9′.3 S
LIT (135° 27′.3)	09 02	Dep	34′.8 W
GMT	20 59	mean lat (from ITP)	43° 45′.25
Initial GMT	18 35	d.long	48′.2 W
Run	02 24	1st run up Lat	N 43° 40′.6
Speed	15	1st run up Long	W 136° 15′.5
Distance Run	36′		
2nd Approx		***2nd run up posn***	
LMT merpass	11 57	d.lat	9′.5 S
LIT (136° 15′.5)	09 05	Dep	35′.5 W

GMT merpass	**21 02**	mean lat (from ITP)	43° 45´.15
Initial GMT	18 35	d.long	49´.1 W
Run	02 27	2nd run up Lat	N 43° 40´.4
Speed	15	2nd run up Long	W 136° 16´.4
Distance Run	36´.75		
		Altitude	
Declination 2100	N 16° 24´.1	Sext Alt	62° 36´.0
d Corrn | + 0.7	0.0	IE	+ 1´.5
Declination	N 16° 24´.1	Obs Alt	62° 37´.5
		Dip	- 7´.1
Setting sextant		App Alt	62° 30´.4
Lat N 43° 40´.4		T Corrn	+ 15´.5
TA = D – L + 90°	62° 43´.7	True Alt	62° 45´.9
		L = D – TA + 90°	N 43° 38´.2
Sext Alt	**62° 33´.8**	From Plot	
IE	+ 1´.5	Dep	1´.3 W
Obs Alt	62° 35´.3	mean lat	43° 39´.3
Dip	- 7´.1	d.long	1´.8 W
App Alt	62° 28´.2		
T Corrn	+ 15´.5	For T bearing of	121° T
True Alt	62° 43´.7	Position Line =	031° T / 211° T
(working back)		***Observed Posn***	
		Latitude	**N 43° 38´.2**
		Longitude	**W 136° 18´.2**

8.6.5 Errors in Astronomical Position Lines

The position lines may be worked out or plotted with error(s). The following are the general errors that may effect the accuracy of the position lines:

- The sextant altitude of a heavenly body should be corrected for index error, dip, refraction, semi-diameter and parallax. Even then, the resulting true altitude may be incorrect due to a combination of the errors of observation and incorrect values of dip and refraction. The resulting error is transferred to the position line when it is plotted
- The Error in the time may be due to:
    - An incorrect reading of the chronometer
    - An incorrect error
    - An error being applied incorrectly.

An Error in time will result in an error in the hour angle. This will lead to an error in the calculated altitude and the intercept, so the position line will be incorrect. The position line may have an error in longitude by 1´of longitude for each 4 seconds of

time error. This error in distance would be greater at the equator than at the poles. Such an error would be zero when the body is on the observer's meridian.

The method of working sights may cause an error in the calculated altitude and therefore affects the intercept in the same way that an error in the observed altitude affects it. This error has two reasons. There is the accumulative and unavoidable error caused by the addition and rounding-off in the formation of quantities taken from the almanac. There is also the error in the method by which the astronomical triangle is resolved. The second error arises because the calculations may be simplified by working to only a few decimal places, and the error varies according to the method used

When time has elapsed between two observations of heavenly bodies, the first position line may be incorrectly transferred for various reasons:

- The course laid down on the chart or plotting sheet may be different to the course made good or there has been inaccuracy of course steered
- Inaccuracy of speed made good and so the distance transferred off of the position line
- Due to the rhumb line itself, the azimuth and intercept should range with the transfer

8.6.6 Cocked Hat

Three astronomical position lines are not likely to pass through the same point due to the errors discussed above. Each position line is displaced parallel to its actual location and a cocked hat is formed. The errors may be equal in magnitude and a sign for each position line, termed the common equal error, e.g. index error. In this case the mathematical construction techniques can be used to resolve the cocked hat.

8.6.6.1 Resolution of Cocked Hat formed by Astronomical Position Lines

Unless the separate errors are known, the true observed position cannot be found. However, if all the errors are assumed to be equal in magnitude and sign, as they would be if, for example, the only source of error lay in an inaccurate value of the index error, then simple constructions to find the fix can be applied.

The construction examples are for two conditions:

- all bodies contained within 180° of azimuth;
- all bodies spread over the horizon – containing azimuth more than 180°

regardless of whether the intercepts are towards, away or a mix of both.

Where the errors are random, the mathematical construction cannot be applied. The only option is to derive the most probable position, the explanation for which is beyond the scope of this book. It should be remembered that the most probable position will be inside the Cocked Hat, with a probability of 25%

In the constructions below, the position lines are displaced either towards the body or away from the body. It is essential to displace all the position lines in the same direction, i.e., either all towards or all away. Additionally, all the offset distances should be the same, e.g., 1´ or 2´. It is not necessary to apply the exact error.

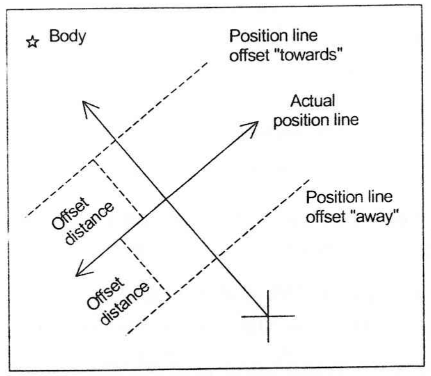

Figure 8.18 - Position Line Offset

Construction for azimuth covering more than 180°

In this case the bodies are well spread over the horizon. All position lines are offset 1´ AWAY.

Bisectors are drawn through the intersection of the actual position lines and the respective intersection of the offset position lines. The point where the bisectors meet is the observed position. The position in this case is within the actual Cocked Hat. The result would have been the same if position lines were offset TOWARDS.

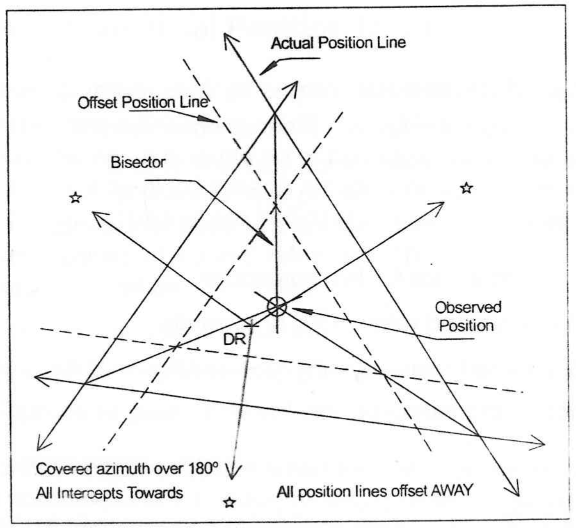

Figure 8.19 - Observed Position Within Actual Cocked Hat

Construction for azimuths covering less than 180°

In this case the bodies are on one side of the horizon. All position lines are offset 1´ AWAY.

Bisectors are drawn through the intersection of the actual position lines and the respective intersection of the offset position lines.

The point where the bisectors meet is the observed position. The position in this case is outside the actual Cocked Hat. The result would have been the same if the position lines were offset TOWARDS.

Just by observation of the angle contained within azimuth, mariners can determine where the position could be in case a cocked hat results after plotting.

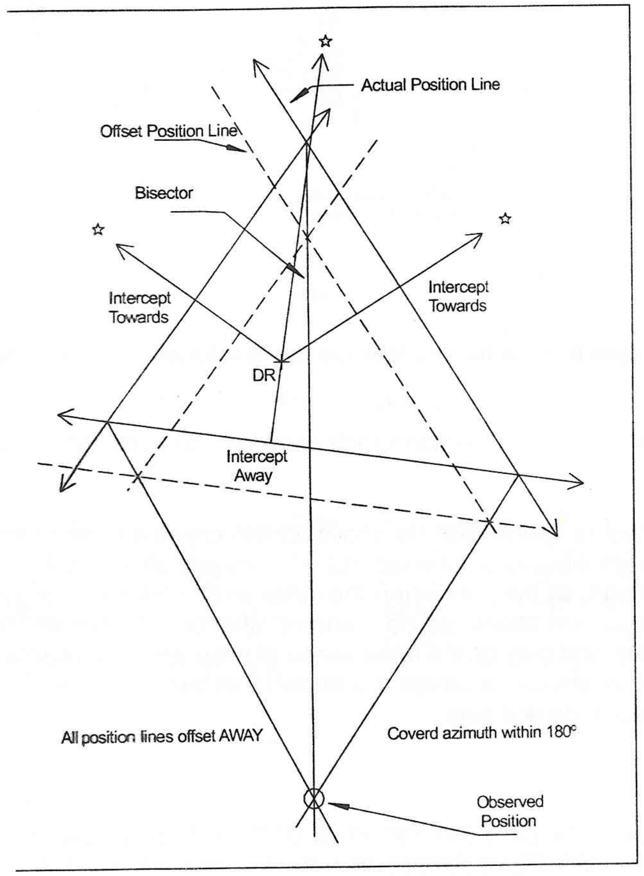

Figure 8.20 - Observed Position Outside Actual Cocked Hat

Alternate method

It is not essential to carry out elaborate construction. All that is required is the bisection of the angles at the intersection of position lines in the appropriate direction. Instead of offsetting the position lines, the angles at TOWARDS or AWAY direction can be bisected.

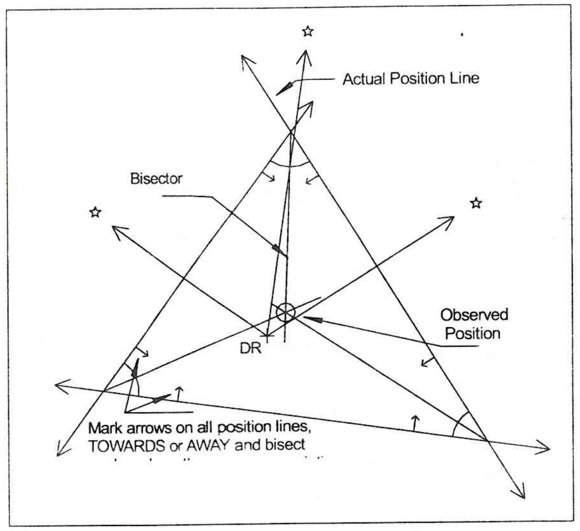

Figure 8.21 - Alternate Method for Resolution of Cocked Hat

This section demonstrates the importance of taking star sights all round the horizon if possible.

It is very important to realise that the above constructions are valid only when the errors in the zenith distances obtained from the sextant observations are equal in magnitude and sign, as they are when the index error is incorrect or applied the wrong way. The constructions can be made whether or not other errors are taken into consideration and may give a false sense of accuracy. No reliance should be placed on such constructions unless it is known that the total errors in each intercept are equal in magnitude and sign.

Example 8.12

At 1920 hrs, a vessel in DR Posn 25° 30′ S, 073° 42′ E, on a course of 230°T at 22 knots, makes the following observations:

	Time	*True Alt*	*Azimuth*	*Intercept*
Star A	*1950*	*25° 48′*	*282°T*	*2.5 T*
Star B	*1945*	*41° 13′*	*140°T*	*0.6 A*
Star C	*1935*	*38° 42′*	*350°T*	*4.5 A*

The DR was used for all intercepts. Determine the observed position at 1935.

Solution and Comments

The runs for the three stars from 1935 are as follows:

Star A 1935 – 1950 = 15 minutes back = 5′.5 run-back
Star B 1935 – 1945 = 10 minutes back = 3′.67 run-back
Star C 1935 – 1935 = 0

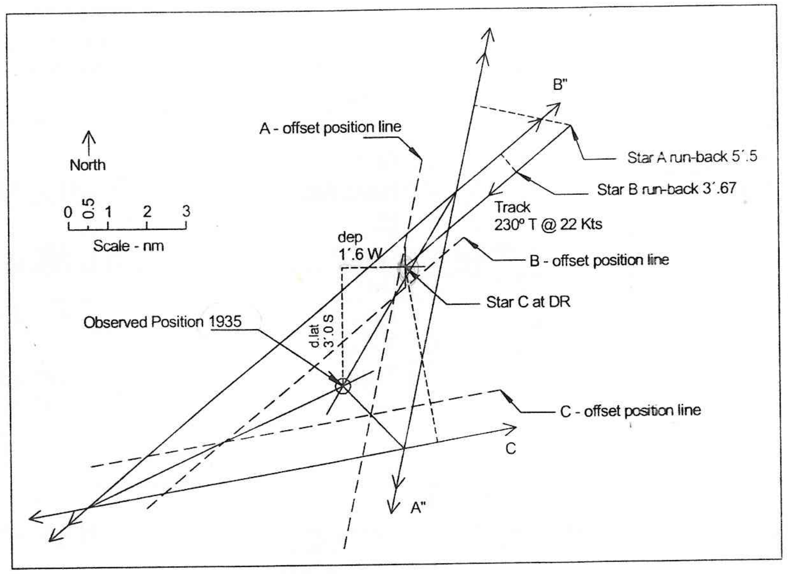

Figure 8.22 - Plot for Example 8.12

From the plot:

d.lat	= 3′.0 S		departure	= 1′.6 W
mean lat	= DR lat + ½ d.lat		= 25° 30′ S + 1′.5 S = 25° 31′.5 S	
d.long	= dep / cos mean lat		= 1′.6 / cos 25° 31′.5	= 1′.8 W
	DR lat	25° 30′.0 S	long	073° 42′.0 E
	d.lat	3′.0 S	d.long	1′.8 W
Position	1935	**25° 33′.0 N**		**073° 40′.2 E**

8.6.7 Polaris

It is important to discus Polaris (also known as α Ursæ Minoris) separately. Polaris is not exactly at the north celestial pole and describes a small circle of approximately 1° radius. Had it been at the north celestial pole, its true altitude would provide the latitude of observer in the northern hemisphere and its bearing would provide reference to the true north.

Example 8.13

On 5th May 2006 at 0330 (GMT 05h 29m 42s), in DR 48° 46´N 023° 12´W, Polaris was observed at a sextant altitude of 48° 36´. Determine the position line and the latitude through which to draw the position line on the observer's meridian. The index error is 0´.7 off the arc, height of eye is 15.7m, course 090°T and speed 18 knots.

Solution

DR Latitude	N 48° 46´.0	Date and Z T	05 May'06 0330
DR Longitude	W 023° 12´.0	Zone +2	0200
Course / Speed	090°T / 18 kts	Greenwich date	05 May'06 0530
GMT	05 29 42	Altitude	
GHA Aries	297° 55´.9	Sext Alt	48° 36´.0
Increment	7° 26´.7	IE	+ 0´.7
Sub-total	305° 22´.6	Obs Alt	48° 36´.7
Longitude	W 023° 12´.0	Dip	- 7´.0
- 360°		App Alt	48° 29´.7
LHA Aries	282° 10´.6	T Corrn	- 0´.9
		True Alt	48° 28´.8
		ao	1° 18´.6
		a1	0´.6
		a2	0´.4
Azimuth	001°.0 T		-1° 00´.0
Position line	091° T ~ 271° T	Latitude	N 48° 48´.4

It must be remembered that the latitude obtained is not the latitude of the observer and is only a point on the observer's meridian through which to plot the position line.

Author's Note

Satisfaction about the performance of electronic navigational aids can be obtained through frequent cross checks using celestial navigation methods. This way the navigator remains in practice and is able to find out where the ship is, or how the equipment is performing, without having to look at a fancy box every time. It is possible, though not likely, that the electronic aids to navigation will fail, or be switched off. As an element of risk assessment, the preparedness to deal with any situation is an important step towards overcoming or tackling the problem itself. In the event of failure or malfunction of electronic aids to navigation, the basic practices of celestial navigation will have to be improvised. The integrity of modern aids to navigation is not at question, but the confidence gained to navigate without them is a primary skill.

9 Electronic Navigation Aids

Recent decades have seen great advances in the techniques of navigation, largely as a result of technological development, especially in the fields of space and electronic computers. Although it is essential to stay abreast of developments, the basic principles of marine navigation remain unchanged. Due care must be taken to set up the navigational aids (navaids) properly, to operate them correctly, to apply relevant errors and to plot positions accurately. This chapter covers the principles of operation and the precautions to be taken during navigational use.

9.1 Satellite Navigation Systems

9.1.1 Global Positioning System (GPS)

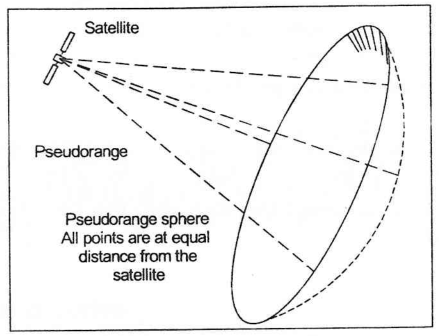

Figure 9.1 - Section of Pseudo-Range Sphere

GPS is based upon the measurement of the distance between satellites in orbit and a receiver. These distances are range spheres that intersect at the receiver for calculation of the position. The receiver measures the propagation time of the satellite signals being received. The ranges measured are not true, but are pseudo-ranges as they contain the receiver clock offset error. The receiver processor can resolve the three range equations to remove the effects of receiver clock offset and provide a 2-D fix, or it can resolve four pseudo-range equations to provide a 3-D fix.

The systems (GPS and others) in current use or planned for the future are based upon the measurement of time it takes for a radio signal to travel from a satellite to a receiver (Distance = Velocity x Time). These systems provide precise position, velocity and time information.

9.1.1.1 Frequencies and Codes

All transmissions from GPS satellites are on pseudo-random noise sequence-modulated frequencies, L1, L2, etc. In the past, GPS satellites transmitted on two frequencies, L1 = 1575.42 MHz and L2 = 1227.60 MHz, but modernisation plans have allowed the use of a third frequency from 2005, L5 = 1176.45 MHz. Satellites transmitting the full range of L2 and L5 signals will be fully operational by 2011 and 2015. The basic reason for using two frequencies was that dual frequency receivers can correct for effects of atmospheric refraction. L1 is less affected by ionospheric refraction error than L2 or L5 and is expected to remain the most important civil frequency.

GPS can provide a Standard Positioning Service (SPS) or a Precise Positioning Service (PPS). SPS is based upon the Coarse Acquisition (C/A) Code. Presently the C/A code is being transmitted on the L1 frequency, but plans are in place also to transmit it on the L2 frequency in order to provide a second civil signal. PPS is based upon the Precise (P) Code, which is transmitted on both L1 and L2 frequencies. It is reserved for military use. Additionally, Y code has been developed separately from the C/A code for broadcast on a regional basis.

Over the next few years, the number of navigation signals will increase from three to seven. C/A code can be received by all types of receivers, where as P code is encrypted for reception only by specific receivers. All codes carry a navigation message containing satellite ephemeris data, atmospheric propagation correction data and satellite clock bias. The new signals will have substantially better characteristics, including a pilot carrier, much longer codes, use of forward error correction and a more flexible message structure with much better resolution.

The system is designed to provide a minimum of four satellites above 9.5° elevation anywhere in the world. In most locations there are more than four satellites in view and the receiver is then able to select the four with the best GDOP (see 9.1.9.4) for the most accurate position.

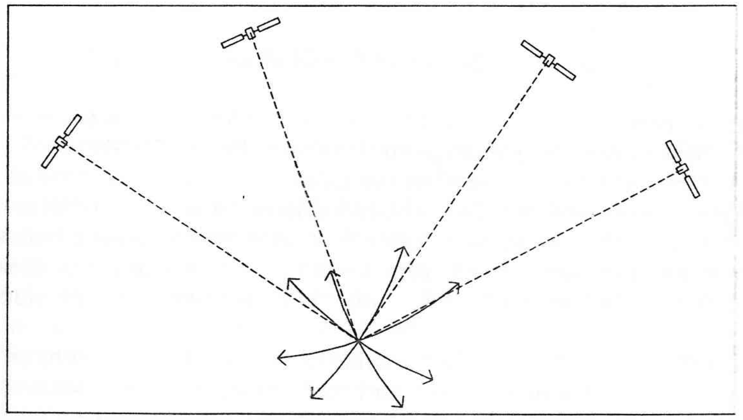

Figure 9.2 - 4 Ranges for a 3-D Fix

9.1.1.2 GPS Architecture

The system comprises of:

- A Master control station
  This has equipment and facilities required for satellite monitoring, telemetry, tracking, commanding, controlling, uploading and navigation message generation
- Monitoring stations
  These passively track the satellites, accumulate ranging data from the satellites and relay to the Master station
- Ground antennas
  Which are used for transmitting and receiving satellite control information
- Satellite constellation
- Receiver units
  These can vary greatly in function and design, depending upon their purpose.

9.1.2 GLONASS

This system is planned and controlled by the Russian Federation and is quite similar to the GPS. However, there are some differences. It is based upon the Earth Centred Earth Fixed co-ordinates as opposed to the Keplerian parameters used for GPS. System architecture is also similar to that of GPS.

9.1.2.1 Frequencies and Codes

GLONASS satellites transmit on two carrier frequencies, L1 and L2, and each satellite transmits on different frequencies. L1 ranges from 1602.5625 MHz to 1615.5 MHz with increments of 0.5625 MHz. L2 ranges from 1246.4375 MHz to 1256.5 MHz with increments of 0.4375 MHz. Each frequency transmitted by the satellites is modulated by one or both of the precise or coarse acquisition (C/A) codes.

The GLONASS administration plans to reduce the bandwidth utilisation. The satellites in the same plane and separated by 180° are to transmit on the same frequency.